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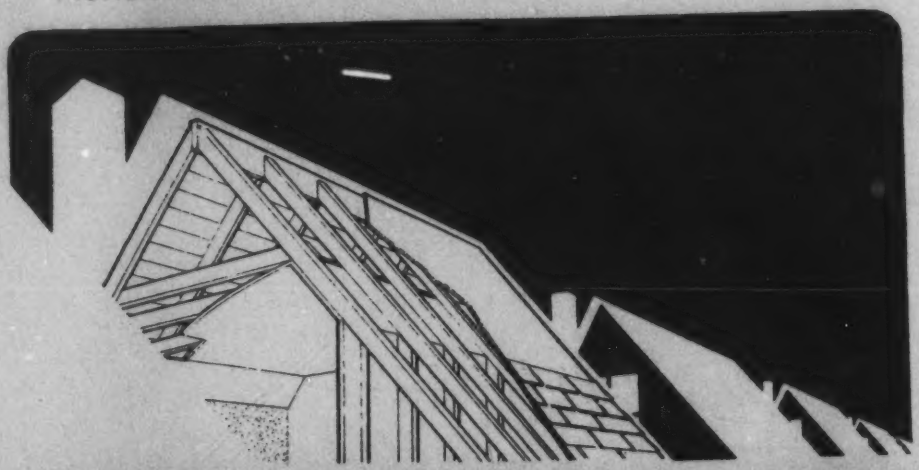
Student Manual

BUILDING CONSTRUCTION FOR FIRE SUPPRESSION FORCES:

Noncombustible and Fire-Resistive Construction



National Fire Academy / National Emergency Training Center

FEM 1.8:

READEX FICHE

Building Construction for Fire Suppression Forces:

Noncombustible and Fire-Resistive Construction

FEDERAL EMERGENCY MANAGEMENT AGENCY
NATIONAL EMERGENCY TRAINING CENTER
NATIONAL FIRE ACADEMY

FOREWORD

The Federal Emergency Management Agency (FEMA) was established in 1979 and is directed by The Honorable Julius W. Becton. FEMA's mission is to focus federal effort on preparedness, mitigation, response, and recovery of emergencies encompassing the full range of natural and man-made disasters.

FEMA's National Emergency Training Center in Emmitsburg, Maryland, includes the National Fire Academy, the United States Fire Administration, and the Emergency Management Institute. This center is directed by James P. McNeill, Associate Director for Training and Fire Programs.

To achieve the Academy's legislated mandate (under Public Law 93-498, October 29, 1974) "to advance the professional development of fire service personnel and of other persons engaged in fire prevention activities," the Field Programs Division has developed an effective program linkage with established fire training systems which exist at the state and local level. It is the responsibility of this division to support and strenghten these delivery systems. Academy field courses have been sponsored by the respective state fire training systems in every state.

This course, along with the Field Programs course, "Building Construction for Fire Suppression Forces: Principles, Wood and Ordinary Construction" is designed to improve the ability of students to assess building stability and resistance to fire. This will aid students in protecting the lives of firefighters and community residents, while improving operational effectiveness through more complete and accurate "size-ups". As our resources and experience are matched with those brought to the classroom by both students and instructors, each course delivery will fulfill in part the Academy's mission--to upgrade the skills of our nation's fire service.

The staff of the Training and Fire Programs Directorate is proud to join with state and local fire agencies in providing educational opportunities to the members of the nation's fire services.

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COURSE GOALS

The student will recognize the key features of noncombustible and fire-resistive structures that affect emergency operations. The fire behavior of steel and concrete will be presented so that the effect of their presence in noncombustible or fire-resistive structures may be better anticipated. The student will learn basic principles that apply to the spread of fire and products of combustion in these structures, and study special problems with common types of building elements and interior finish. Testing methods for various interior finishes and possible differences between "real life" contexts and the test situation will be highlighted. The unique problems of conducting emergency operations in buildings under construction will be addressed.

Through this training, students will be able to reduce firefighter injuries in building fires and improve operational effectiveness. Secondary benefits include: improved pre-fire plans; better procedures for collecting and "institutionalizing" information on buildings; improved communication with building construction and fire; and more effective department training based on informed post-incident analysis and thorough familiarity with relevant features on area buildings.

STANDARDS

The National Fire Academy strongly supports the standards-making process of the National Professional Qualifications Board for the Fire Service, which operates under the jurisdiction of the Joint Council of National Fire Service Organizations.

The Academy, in its preparation of this course, reviewed the appropriate professional qualifications standards to determine which specific standards were to be addressed in whole or substantially in part.

Those addressed in whole or substantially in part are:

1001 Firefighter Professional Qualifications

3-10.2 The firefighter shall identify the dangers present, and precautions to be taken in performing ventilation.

3-15.1 The firefighter shall identify dangerous building conditions created by fire.

4-12.4 The firefighter shall identify dangers of search and rescue missions in tunnels, caves, construction sites, and other hazardous areas.

5-12.1 The firefighter shall list five indicators of structural instability.

1021 Fire Officer Professional Qualifications

2-8.2 The Fire Officer I, given actual or simulated fire inspection reports for each of the following occupancies, shall evaluate the reports and identify the construction features which might contribute to the spread of fire, heat, and smoke throughout the building or from one building to another:

(a) Public assembly

(b) Educational
  (1) Residential
  (2) Nonresidential

(c) Institutional

(d) Residential

(e) Stores and offices

(f) Basic industry

(g) Manufacturing

(h) Storage

(i) Special properties

2-8.3 The Fire Officer I shall demonstrate knowledge of the characteristics of basic building materials and their behavior under fire conditions.

2-10.6 The Fire Officer I, given a simulated interior fire situation, shall:
(a) describe how fire may extend within the building
(b) describe how to control the spread of fire within the building.

2-10.7 The Fire Officer I, given a simulated exterior fire situation, shall:
(a) evaluate the situation

(b) describe how to control the spread of fire to keep it from extending to adjacent buildings.

THE INTEGRATED EMERGENCY MANAGEMENT SYSTEM

The Integrated Emergency Management System (IEMS) is a long-term, all-hazard concept for improving the program implementation and development of emergency management capabilities at the state and local levels. It is a process for applying comprehensive emergency management concepts to "real world" emergency plans and capabilities. It formally recognizes the roles of the fire service in responding to the full range of emergencies at the local level.

Its specific objectives are to:

1. Save lives and protect property threatened by hazards.
2. Reduce duplication of efforts and resources.
3. Increase jurisdictional flexibility in upgrading the capacity to handle potential hazards.
4. Integrate FEMA support and objectives with those state and local operational requirements.

Viewed in this manner, it becomes clear that existing fire service programs such as the Incident Command System (ICS) are part of the broader concept of IEMS. ICS-IEMS identifies the need for "baseline" fireground command systems to provide for a predictable, coordinated, effective and acceptable response to emergencies of all types by the fire services of this country.

The IEMS approach recognizes that there are certain characteristics and requirements which are common across the full spectrum of emergencies--evacuation, sheltering, provision of food and medical supplies, etc. Each of the aforementioned functions requires an operational procedure. ICS is such a procedure to ensure all areas of concern are addressed. FEMA's programs are using the IEMS approach to assist state and local officials in building capability in these areas as a basic foundation for planning, response, recovery, and mitigation of hazards-whether they are related to natural or technological disasters, resource shortages, or war-related national security situations.

IEMS is being introduced to a nationwide network of emergency management organizations representing thousands of jurisdictions, not all confronted by the same hazards, and not all having or requiring the same capabilities. Going through the IEMS process, therefore, will require different levels of effort by each jurisdiction and will result in the identification of different functional areas requiring attention. The process, however, is logical and applicable to all jurisdictions regardless of their size, level of sophistication, potential hazards, or current capabilities.

The goal of the system is to develop and maintain a credible emergency management capabaility nationwide by integrating activities along functional lines at all levels of government, and, to the fullest extent possible, across all hazards. It should be kept in mind that the IEMS process is a means of improving capability and is not an end in itself. The various steps in the IEMS process are intended to serve management at each level of government by providing basic information upon which reasonable and justifiable plans can be made and effective action taken to increase emergency management capability nationwide.

Although IEMS underscores capability development, the process recognizes that current operations must be conducted according to existing plans and with existing resources, and that these operations can contribute to the developmental effort. The process, therefore, includes two paths: one focusing on current capabilities and activities, and the other emphasizing capability improvement.

COURSE SCHEDULE

UNIT	TITLE	TIME
Introduction	Introduction	1 hour, 10 minutes
One	Steel as a Structural Material	2 hours
Two	Concrete as a Structural Material	1 hour, 45 minutes
Three	The Principles of Fire Growth in Buildings	2 hours, 45 minutes
Four	The Principles of Smoke Spread in Buildings	2 hours, 55 minutes
Five	Special Problems of Buildings Under Construction	1 hour, 35 minutes
	TOTAL CLASSROOM TIME:	12 hours, 10 minutes

This course is designed for approximately 12 hours of student contact. These contact hours **do not** include time for registration, introduction, breaks, meals, student examinations, course evaluations, and the distribution of certificates. With these activities, the actual time required will be over 16 hours.

Introduction

OBJECTIVE

The student will cite key features of noncombustible or fire-resistive buildings that affect emergency operations.

Enabling Objective 1: The student will list several fire and life safety concerns that exist in noncombustible and fire-resistive structures.

Enabling Objective 2: The student will explain fire service implications of some of the major trends in building design in the last century.

Introduction

Overview

Total Time: 1 hour, 10 minutes *

Course Introduction
(Lecture)

A. Historical Perspective on Fire Resistance
(Slide/Lecture)

B. Key Terms
(Lecture, Discussion)

C. Murphy's View of Fire Resistance
(Lecture, Discussion)

*Times do not include breaks.

INTRODUCTION

Objective

Objective

The student will cite key features of noncombustible or fire-resistive buildings that affect emergency operations.

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Course Introduction

Goal

A. Historical Perspective on Fire Resistance

1. Early fire-resistive buildings (1870-1930).

2. Fire-resistive buildings (1920-1940).

a. Massiveness.

b. Design features.

3. Modern structures (Post World War II).

Some key trends affecting modern structures:

B. Key Terms

[Definition source for "noncombustible" is NFPA 220, Building Construction.]

1. **Noncombustible material:** A material which, **in the form in which it is used and under the conditions anticipated,** will not ignite, burn, support combustion, or release flammable vapors, when subjected to fire or heat.

   Materials reported as noncombustible, when tested in accordance with the **Standard Method of Testing for Noncombustibility of Elementary Materials,** ASTM E-136, shall be considered noncombustible materials.

2. **Limited combustible:** A category devised in part to properly incorporate materials such as gypsum wallboard, commonly called drywall.

3. **Fireproof.**

4. **Fire resistance:** The capacity of a material or construction to withstand fire or give protection from it; characterized by its ability to confine a fire and/or to continue to perform a structural function. (Same a s "fire endurance.")

5. **Fire-resistance rating:** The time in hours that a material or construction can withstand fire exposure, as determined in conformity with generally accepted standards, or from information derived from standard tests.

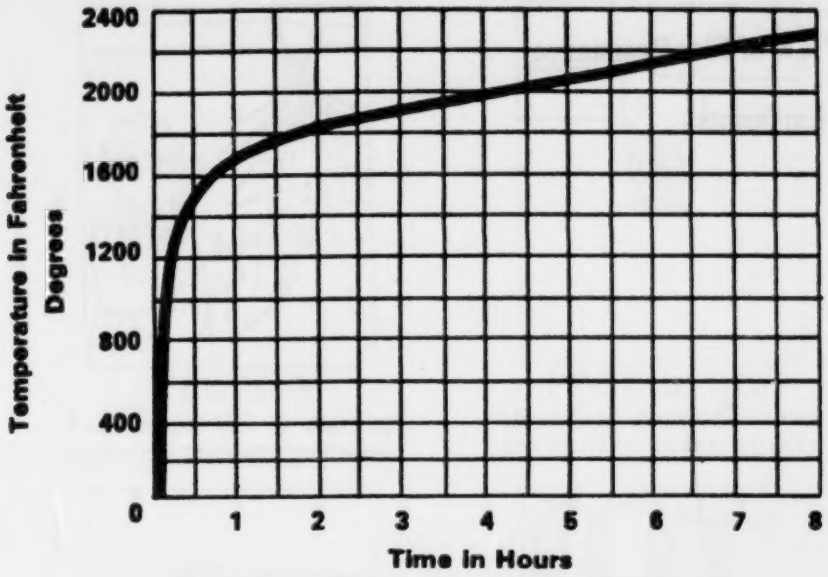
   • **Fire-resistive construction:** Building construction in which the structural members (including walls, partitions, columns, floors, and roof) are of noncombustible materials that meet or exceed prescribed requirements by the applicable code.

   • **Noncombustible construction:** Construction in which structural members are of noncombustible materials and assemblies, but which does not meet requirements for fire-resistive construction in the applicable code.

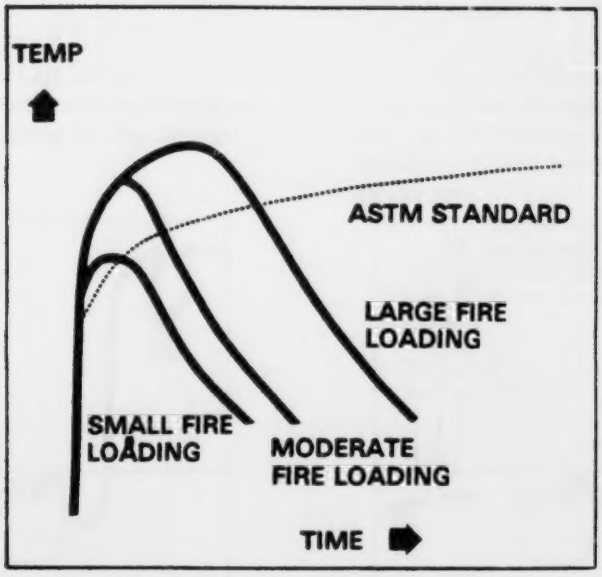
	Ability to Sustain Load	Flame Passage	Hose Stream Effect	Steel Temperature	Heat Transmission
Floors and Roofs					
a. Restrained	•	•		•	•
b. Unrestrained	•	•		•	•
Walls					
a. Bearing	•	•	•		•
b. Nonbearing		•	•		•
Columns	•			•	
Beams					
a. Restrained	•			•	
b. Unrestrained	•			•	

Acceptance Criteria for ASTM E-119

6. Requirements for fire resistance rating.



Standard Time-Temperature Curve



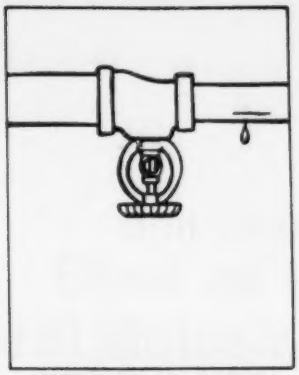
More Realistic Time-Temperature Curves for Modern Buildings

C. Murphy's View of Fire Resistance

Discussion points:

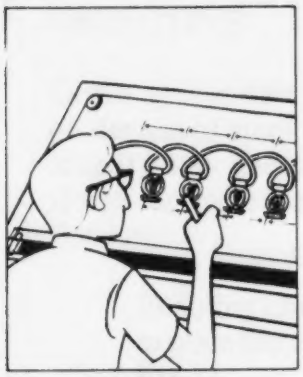
TESTING

Test approval is earned under controlled conditions.



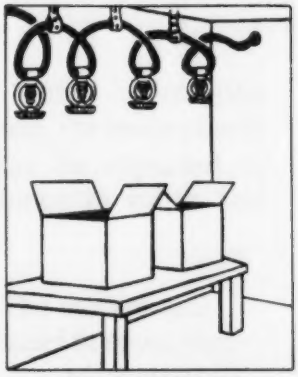
PRODUCTION

Materials produced may not all be up to test quality.



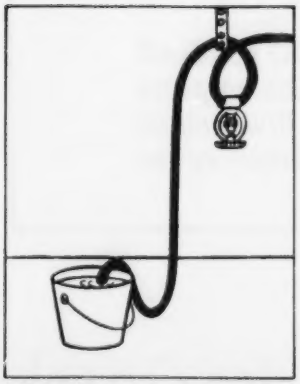
DESIGN

The architect may introduce alterations in the design.



PLANNING

The contractor may make an unauthorized substitution in the interest of economy.



INSTALLATION

The workman may think of an easier way to get the same result.

INSPECTION

The inspector may not notice the changes or see their significance

Murphy's View of "Fire-Safe" Design

Unit One:
Steel as a Structural Material

OBJECTIVE

Given appropriate visual or verbal information on the use of steel in a structure, the student will identify key factors that may be expected to lessen or increase its resistance to stress and fire.

Enabling Objective 1: The student will explain the reaction of steel to stress and fire.

Enabling Objective 2: The student will explain the effect of key factors on the fire and stress reaction of steel.

Enabling Objective 3: Given visual representations or descriptions, the student will ascertain presence and type of fire protection and cite fire concerns.

UNIT ONE: STEEL AS A STRUCTURAL MATERIAL

Overview

Total Time: 2 hours*

A. Characteristics of Steel
(Lecture)

B. Fire Concerns
(Lecture, slides, discussion)

C. Key Factors in Fire Performance of Steel
(Slide, lecture)

D. Steel Framing
(Lecture)

E. Connections for Steel Members
(Lecture)

F. Fire Protection Methods
(Lecture)

G. Concerns on Fire-Resistive Construction Methods
(Table group activity)

H. Fire Concerns for Steel Protection Methods
(Lecture, discussion, slides)

* Times do not include breaks.

UNIT ONE

Objective

Given appropriate visual or verbal information on the use of steel in a structure, the student will identify key factors that may be expected to lessen or increase its resistance to stress and fire.

Enabling Objective 1: The student will explain the reaction of steel to stress and fire.

Enabling Objective 2: The student will explain the effect of key factors on the fire and stress reaction of steel.

Enabling Objective 3: Given visual representations or descriptions, the student will ascertain presence and type of fire protection and cite fire concerns.

A. Characteristics of Steel

1. Advantages compared with other traditional structural materials (wood, concrete, brick).

2. Factors that affect characteristics.

a. Composition.

- **Brittleness:** Tendency to break or fracture without deforming.

- **Ductility:** Tendency to deform before breaking or fracturing, thus giving "warning" before failure.

b. Mechanical working.

- **Cold-working:** Permanently deforming a metal at low temperature, such that there is an increase in hardness and strength.

- **Cold-drawing:** A method of cold-working involving pulling a bar through dies of smaller diameter to produce wire or strands.

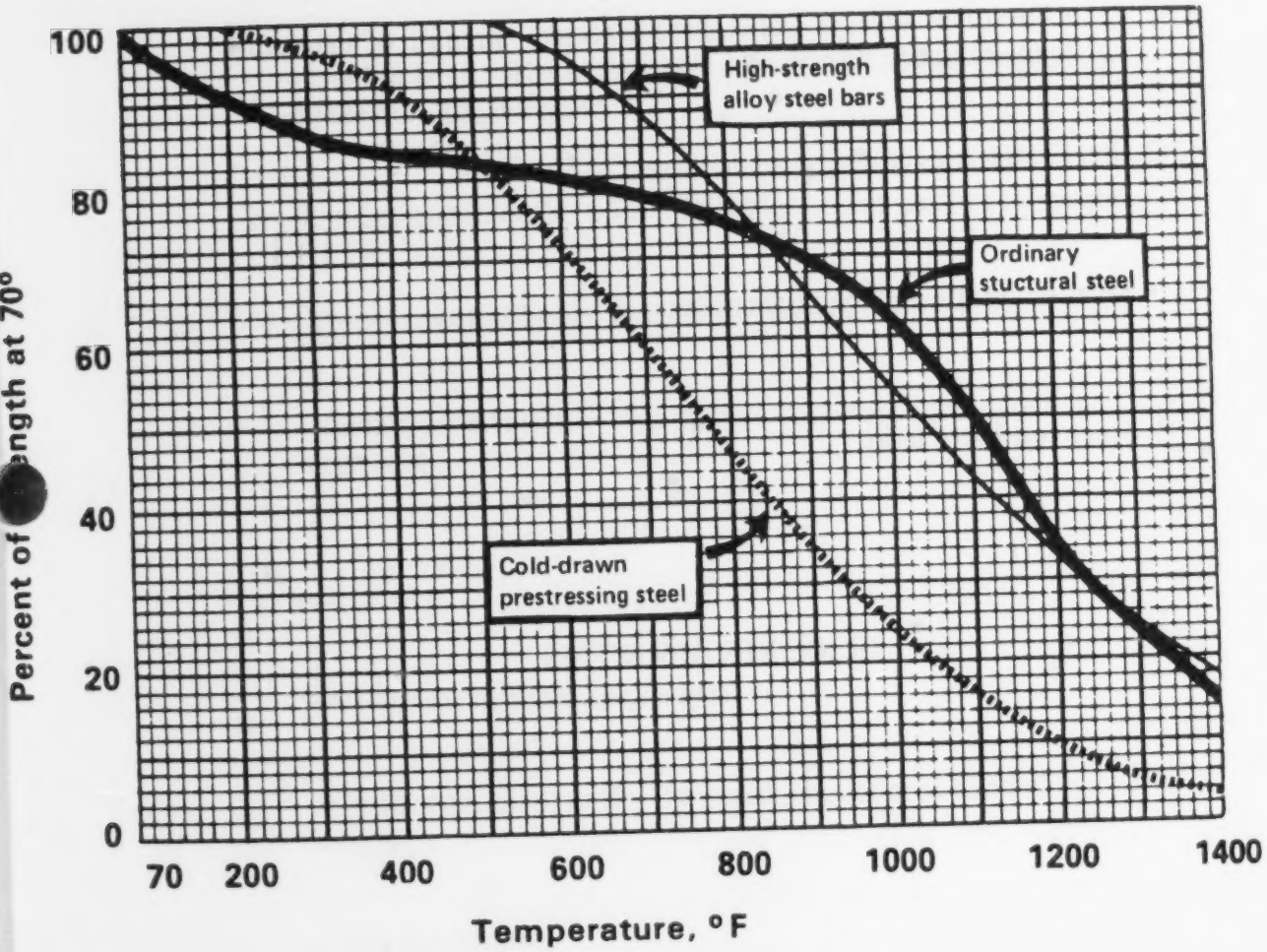
- **Cold-drawn steel:** May be used for tendons in prestressed concrete.

c. Major types of steel used in structural members.

- **Structural steel.**

- **Heat-treated carbon and/or low-alloy steel.**

- **Cold-drawn steel.**



Strength and Temperature Relationship for Three Steel Types

B. Fire concerns

1. **Steel loses strength** as temperature increases.

   • **Design load:** The maximum load anticipated and planned for by the building designer.

   • **Factor of safety:** Ratio of the expected **strength of a structure** to the expected design load.

2. **Steel softens** as temperature increases.

3. **Steel elongates** at high temperatures.

4. **Steel conducts heat.**

SLIDE REVIEW NOTES

C.Key Factors in Fire Performance of Steel

1. **Type of steel.**

2. **Loading conditions.**

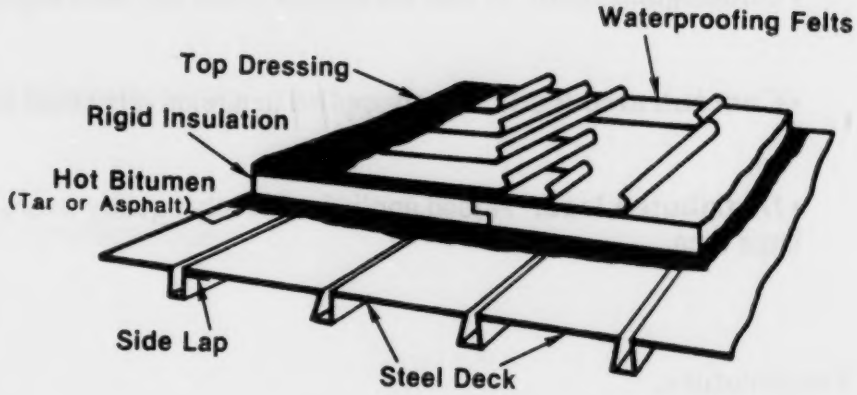
- **Design load:** The maximum load anticipated and planned for by the building designer.
- **Undesigned load:** A load the designer may not have expected.
- **Concentrated load:** A load applied to a relatively small area.
- **Distributed load:** A load applied relatively equally over a large area.

3. **Temperature.**

- A function of **mass** and **shape.**
- **Surface to mass ratio:** Exposed exterior area divided by weight.
- Variable heating.

4. McCormick Place Fire

5. Materials assembly - metal deck roofs.



Steel Deck Roof Assembly

D. Steel framing

1. **Skeleton frame:** A framing system in which all building loads, including the walls, are supported by beams and columns.

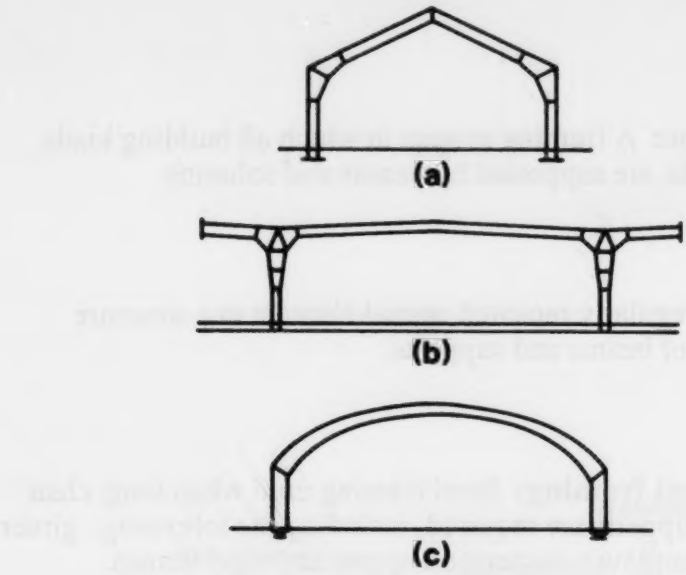
- **Bay:** A regularly repeated spatial element in a structure composed of beams and supports.

2. **Long-span steel framing:** Steel framing used when long, clear spaces between supports are required, including the following: girders, trusses, arches, cantilever-suspension spans, and rigid frames.

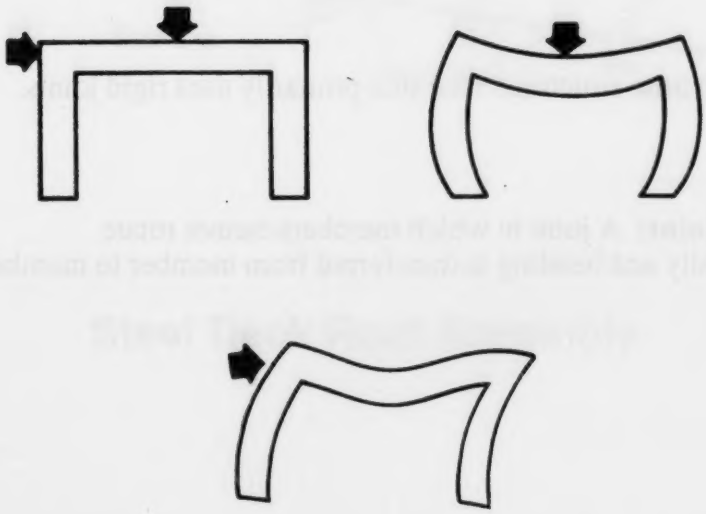
- **Built-up** girders: Beams composed of sections and designed to carry heavier leads than "rolled" beams made all in one piece.

- **Rigid frame** structure: One that primarily uses rigid joints.

- **Rigid joint:** A joint in which members cannot rotate individually and bending is transferred from member to member.



Steel Rigid Frames



Interaction of Members with Rigid Joints

E. Connection for Steel Members

1. Welding.

2. Riveting.

3. Ordinary bolting.

4. High-strength bolting.

F. Fire Protection Methods

1. **Encasement.**

2. **Spray.**

   a. Cementitious mixtures.

   b. Mastic coating.

   c. Fiber spray.

3. **Membrane protection.**

4. Other, less common, methods.

   a. **Water-cooled columns.**

   b. **Flame shields.**

   c. **Separation.**

TABLE GROUP ACTIVITY

CONCERNS IN FIRE-RESISTIVE CONSTRUCTION METHODS

For each of the following four examples of fire-resistive construction (or the example assigned to your group by the instructor):

1. Discuss the key factors in fire endurance for each example. Noting the listed components, consider the principle behind each system. How does it do the work of fire protection?

2. Then list concerns you would have--errors in either installation or use which would impair the construction's fire protection ability. What could go wrong?

Encased Column (Concrete)

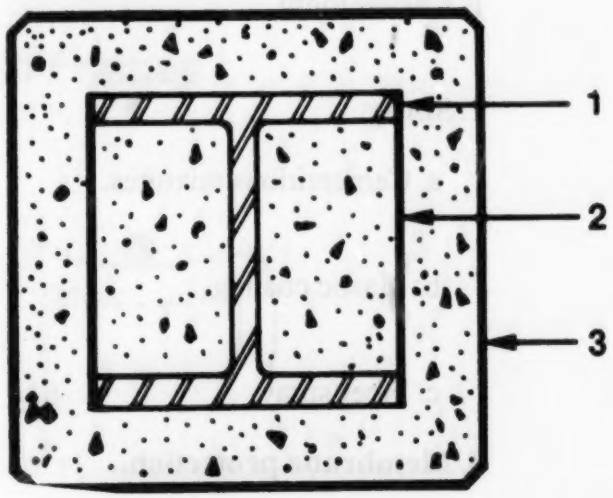
<u>Components</u>

1. **Steel column,** specified type.

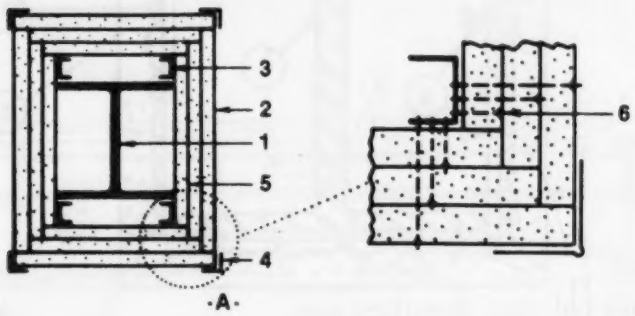
2. **Reinforcement (where required in fire test): Steel wire or mesh.**

3. **Insulation:** Concrete, structural grades. Gypsum-concrete.

<u>Fire Concerns</u>



Encased Column (Gypsum Wall Board)



Components

1. **Steel column,** specific type.

2. **Gypsum wallboard:** one to four layers.

3. **Spacer:** continuous light-gauge galvanized steel stud, typical of most tests. In some assemblies, spacer is located between first layer (in contact with column flanges) and second layer. In others, without spacers, wallboard is in contact with column flanges.

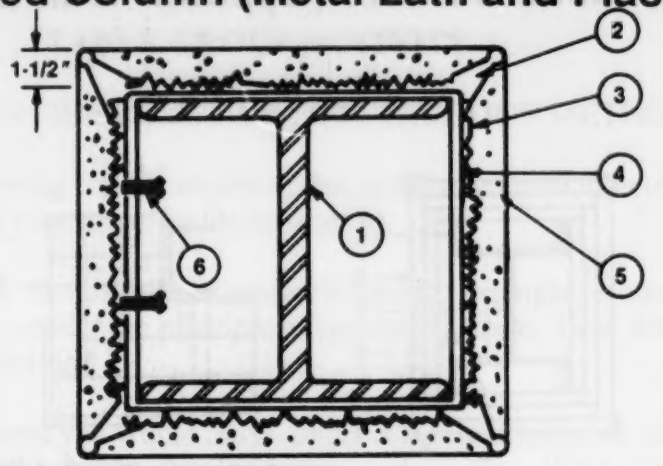
4. **Corner beads:** light-gauge galvanized steel angles.

5. Tie wires (where used).

6. Screws.

Fire Concerns

Encased Column (Metal Lath and Plaster)



Components

1. **Steel building column,** specified size.

2. **Steel corner bead:** placed to provide 1-1/2-inch plaster on face of lath.

3. **Metal lath:** Diamond mesh, 3.4-lb/sq. yd. expanded steel. Lapped 1 inch and tied at 6-inch vertical spacings with 18 SWG galvanized steel wire.

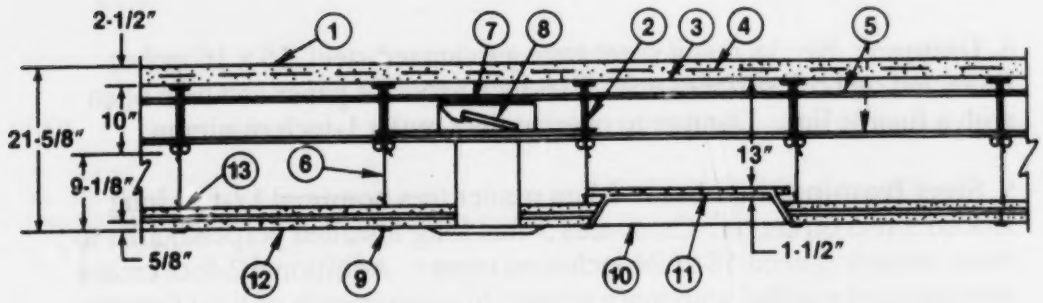
4. **Furring channel:** 3/4-inch cold-rolled steel spaced at approximately 2-foot vertical spacings. Ends lapped at least 3 inches and double tied.

5. **Plaster:** scratch coat, 2 cubic feet, and brown coat, 3 cubic feet of perlite aggregate to 100 lb. of fibered gypsum. Hand applied. Finish coat, 1/16-inch total thickness measured to surface of lath is 1-1/2 inches.

6. **Wire:** no. 18 SWG galvanized steel.

Fire Concerns

2-Hour Rated Ceiling Assembly



Components

1. **Normal-weight concrete:** Siliceous aggregate, 153 pounds per cubic foot unit weight 4,000 pounds per square inch compressive strength.

2. **Steel joists:** Type 10J2 minimum size; spaces 24 inches on center, welded to end supports.

3. **Metal lath:** 3/8-inch rib, 3.4 pounds per square yard expanded steel; tied to each joist at every other rib with 13 British standard wire gage lath clips, and midway between joists at side lap with 18 British standard wire gage galvanized steel wire. As an alternate, corrugated-steel deck 9/16 inches deep, 28 MSG min. galv. may be used. Welded to support 15 inches on center using welding washers. The concrete thickness is measured from the surface of the concrete to the top of the steel deck corrugations.

4. **Welded wire fabric:** 6 x 6--W1.4 x W1.4.

5. **Bridging:** Steel bars, 1/2-inch diameter, welded to top and bottom chords of each joist.

6. **Hanger wire:** Number 12 British Standard wire gage galvanized steel, maximum spacing 48 inches on center along main runners, adjacent to the intersection of suspension members, at four corners of fixtures, and at centers of all 5-foot crosstees.

7. **Air duct:** No. 22 metal sheet gage (minimum thickness) galvanized steel. Total area of duct openings not to exceed 57 square inches per 100 square feet of ceiling area. Area of individual duct opening not to exceed 113 square inches. Maximum dimension of opening, 12 inches. Duct supported by 1-1/2-inch 16 metal sheet gage painted steel channels spaced 48 inches on center suspended by 12 British Standard wire gage galvanized steel wire.

8. **Damper:** No. 18 metal sheet gage galvanized steel, 16 x 16 inches. Protected on both surfaces with 1/16-inch asbestos paper and held open with a fusible link. Damper to overlap duct outlet 1-inch minimun.

9. **Steel framing members:** Main runner tees nomimal 12-feet long spaced 5 feet on center. Cross-tees 5-feet long installed perpendicular to main runners spaced 18 or 24 inches on center. Additional 2-foot cross-tees installed parallel with main runners to support ends of light fixtures. Additional 18- or 24-inches cross-tees installed parallel with main runners to support duct outlets, located 9 inches from centerline of outlet.

Maker and type specified.

10. **Fixtures, recessed light:** Bearing listing mark. Fluorescent lamp type, steel housing, 2 by 4 foot size. Fixtures spaced so their area does not exceed 24 square feet per 100 square feet of ceiling area. Wired in conformance with the National Electrical Code. Fixtures and ballasts must be considered for these ambient temperature conditions before installation.

Maker and type specified.

11. **Fixture protection--acoustical material:** 5/8-inch thick, cut into pieces to form enclosure, trapezoidal in cross section, approximately 1/2 inches longer and wider than the fixture with sufficient depth to provide at least 7/8-inch clearance between the fixture and the enclosure.

Maker and type specified.

12. **Acoustical material:** Nominal 24 by 60 inch or 18 x 60 inch lay-in panels. Border panels supported by 26 metal sheet gage painted steel border channel, 1-5/8 inch 1 deep, with a 1/2-inch top flange and 1-inch bottom flange. (S)=surface perforations, (P)=through perforations.

Maker and type specified.

13. **Hold-down clips:** number 28 metal steel gage spring steel, 1-1/4 inches wide, 1-inch high, 3/4-inch deep. Two clips uniformly placed over bulb of crosstee along 60-inch side of acoustical panels. One leg of each clip to be cut off when placed over bulb of crosstree adjacent to each long edge of each light fixture.

Fire Concerns, Example 4

SLIDE REVIEW NOTES

Further notes on fire-protective construction methods:

REVIEW OF FIRE CONCERNS FOR STEEL STRUCTURAL COMPONENTS

Symptom	Concern
Bar joist.	Expect early failure (high surface-to - mass ratio).
Twisting or bowing of joists or beams.	Member is expanding but restricted by rigid connections. It may be about to drop everything.
Steel protected only to a certain height with heavy fire loading or potential for fast, hot fire.	Heat above that point reaching critical temperatures and causing failure (example-McCormick Place).
Limited bearing for beam, especially if dependent on gravity connection.	Expansion or movement due to heat could push it off the bearing plate, causing collapse.
Tall thin columns, especially if unsupported or unprotected.	Tall thin columns are subject to collapse without warning from sudden buckling.
Size of beams--small, thin.	Low mass-early failure.
Long steel spans.	Could expand several inches. Expansion can cause bearing wall to collapse, or rupture flooring, ceilings, or roofing, allowing spread of fire. Eccentric or lateral load may be placed on steel columns, causing collapse.
Cables spanning building (often with turnbuckles).	Indicate weak walls partially dependent on cable supprt. Cables fail early (cold-drawn steel)--collapse possible at relatively low temperature.
Suspended loads.	Members under tension fail sooner than under compression.
Dripping material from roof exposing frame to fire, possibly accompanied by black rolling smoke.	Hot gases from asphalt adhesive used with metal roof deck may promote self-sustaining fire; rapid collapse possible.

Fire protection partially removed (spray knocked or scraped off by workers, etc.).	Structural member exposed: heat conducted to weakest spot. Failure could occur.
Fire in material by column.	Direct impingement by fire may lead to early failure, depending on size of column, proximity and type of materials.
Concrete--encased steel--corner knocked off (by fork lift?) exposing steel.	Heat absorbed at exposed point leading to failure. Or, heat may be conducted to weak point, resulting in failure.
Gypsum board encased steel columns with corner damaged.	Structural steel column will be exposed to fire early, leading to possible failure.
Steel column seemingly out of place where everything else is concrete or masonry.	Indicates structural modifications in which design limitations could be quickly exceeded. Early failure a good possibility.
Cast-iron columns.	Quite brittle, and subject to early, sudden failure without warning, especially when exposed to cool water applied during extinguishing process.
Spliced beams.	Welded or bolted connections are potential weak points, posing failure potential.
Scissor truss.	Natural force tends to kick out at supports. If any part fails, the walls may be pushed out, leading to sudden collapse.
Heavy fire involvement.	Collapse possible.
Vived red, or white bar joist.	Expect immediate collapse.
Bending beam.	Almost impossible to estimate time left before collapse. Leave building. (Note: End constraints are a critical factor in beam stability and consequences of failure.)

Unit Two:
Concrete as a Structural Material

OBJECTIVE

Given appropriate visual or verbal information on the use of concrete in a structure, the student will identify key factors that increase or lessen its resistance to stress and fire.

Enabling Objective 1: The student will list the various classifications of concrete, identifying features, typical uses, and concerns related to the fire and stress reaction of each.

Enabling Objective 2: The student will cite key variables in the fire and stress response of concrete, including design, use, thickness, integrity, loading conditions, and relation to other materials.

UNIT TWO

Overview

Total Time: 1 hour, 45 minutes*

A. **Concrete Composition and Production**
(Lecture, Slides)

B. Concrete Types and Fire Behavior
(Lecture)

C. Concrete Classifications by Casting Site
(Slide Lecture)

D. Classification of Concrete by Reinforcement
(Lecture, Slides)

E. Variables in Concrete Fire Resistance
(Lecture)

F. Construction Identification Activity
(Individual Activity)

*Times do not include breaks.

UNIT TWO

Objective

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A. Concrete Composition and Production

1. Ingredients.

   a. Cement (binding agent).

   b. Water.

   c. Aggregate.

2. Production.

   a. **Mixed.**

   b. **Cast.**

      • Cast: To place liquid concrete in mold of desired shape.

c. **Cured.**

- Curing: The process by which concrete hardens and obtains full strength through a chemical reaction called hydration. Time and temperature are critical factors.

d. Improper placement

B. Concrete Types and Fire Behavior

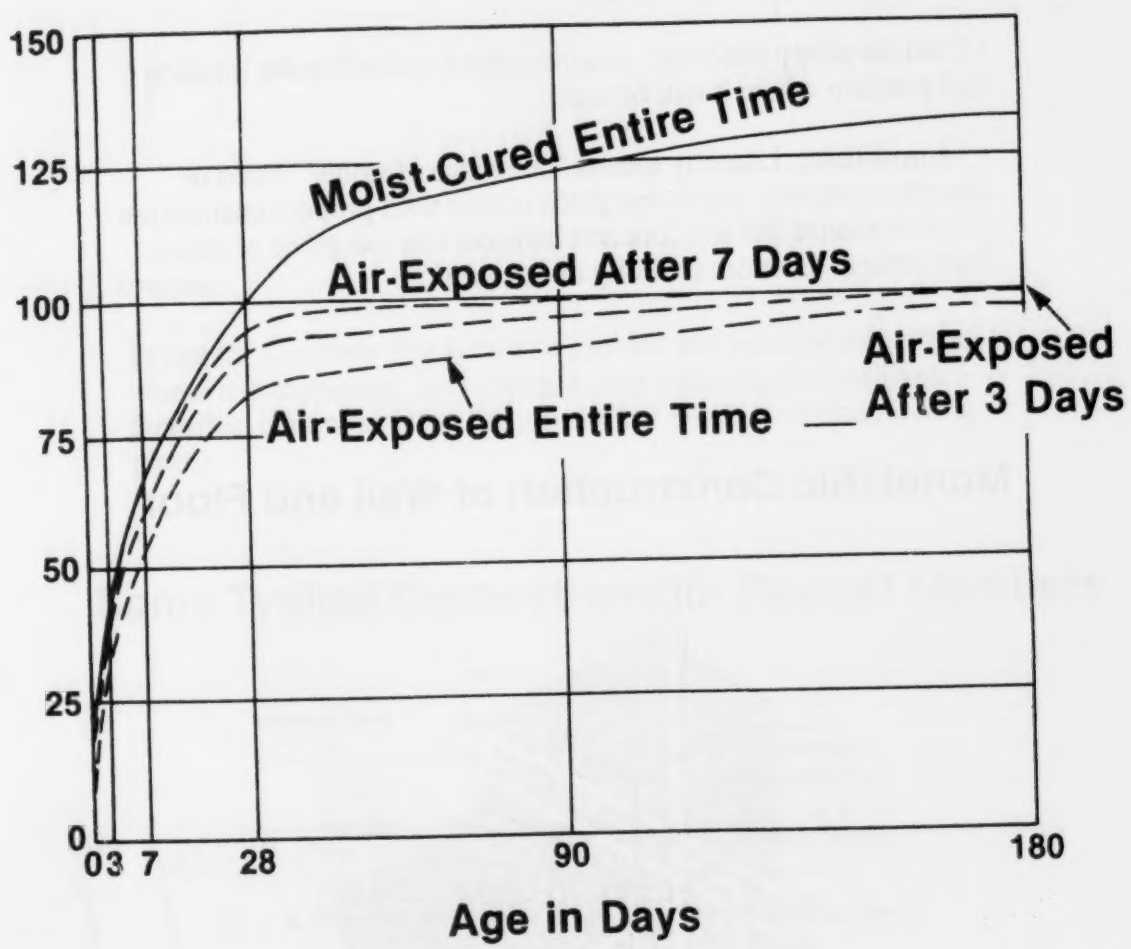
1. **Normal weight.**

- **Creep:** The tendency of concrete to deform over time as a sustained load squeezes water from pores of material.

- **Heat sink:** A material that tends to absorb heat.

- **Spalling:** In reference to concrete, spalling means the loss of surface material due to expansion of moisture when exposed to heat.

2. **Structural lightweight concrete.**



Compressive Strength of Moist-Cured vs. Air-Exposed Concrete

3. **Insulating lightweight concrete.**

4. **Property variations.**

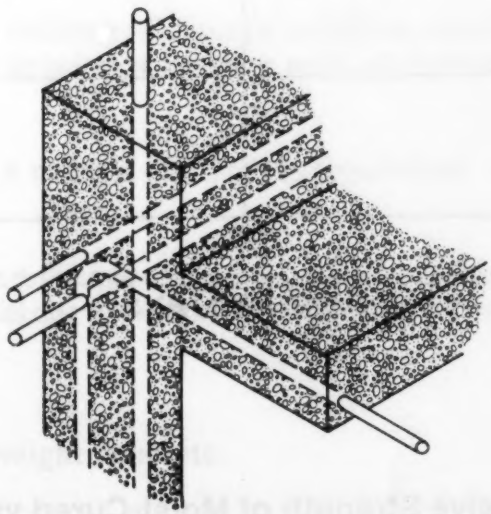
C. Concrete Classifications by Casting Site

1. **Cast-in-place** (or poured in place).

• **Cast-in-place** concrete: concrete that is poured in the location and position where it will be used.

• **Monolithic:** Literally means "one piece of stone." Used to describe concrete cast in one piece or cast with proper construction joints to ensure that the concrete behaves like one piece of stone. May refer to an entire building or one section.

Monolithic Construction of Wall and Floor

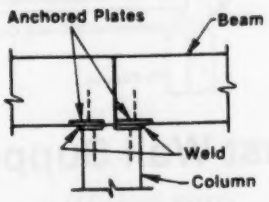


• **Continous slip-forming:** A rapid method of poured-in-place construction in which concrete is poured continually as forms move upward to ensure continuous casting.

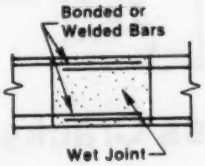
2. **Precast.**

Precast: Concrete that is cast or molded at a location other than where it is to remain. Includes not only units transported from factories, but units cast at the job site but not in their final resting place.

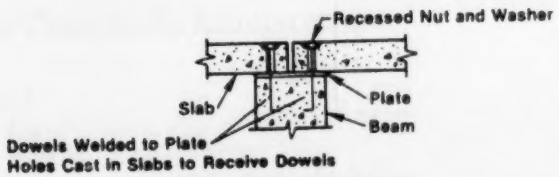
Some Typical Connections for Precast Members



a. Matching Plates

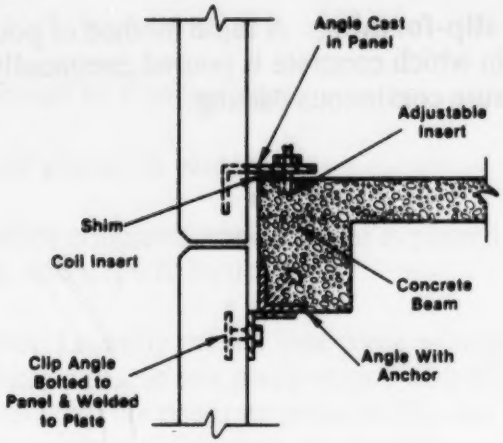


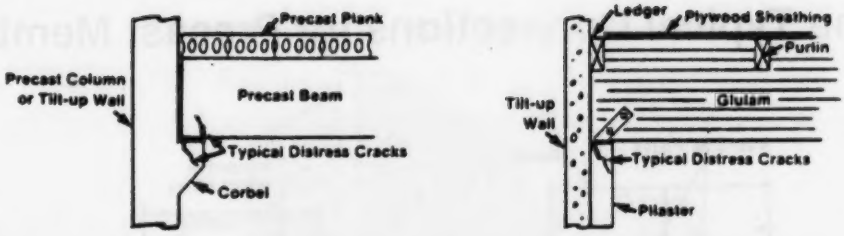
b. Overlapping Bars



c. Slabs Bolted to Beams

A Typical Curtain Wall Attachment





Distress Cracks in Precast Wall Supports

- Special types of precast structures:

  - **Panel construction.**

    . **Panel construction:** A form of low-rise construction in which walls are bearing, and walls and floors are joined by cast-in-place joints.

  - **Tilt-up.**

    . **Tilt-up:** A type of precast construction in which wall panels are cast on the ground along the outside perimeter of the building, then tilted into place and attached.

  - **Lift-slab.**

    .**Lift-slab:** A form of construction in which columns are erected to full height, and all floors cast at bottom of structure with bond breakers between them. Floors are then jacked into position.

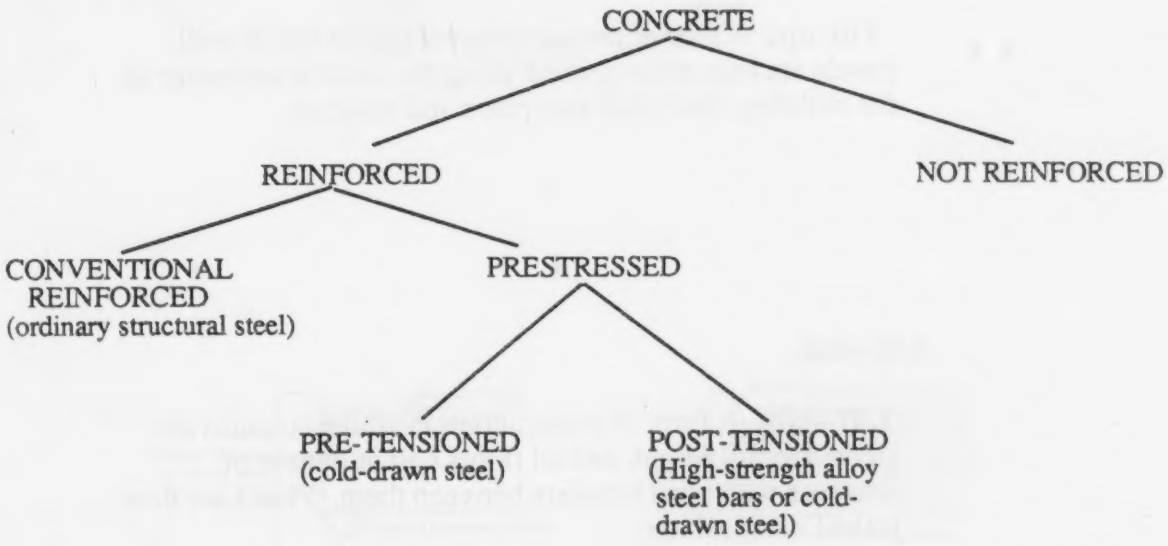
D. Classification of Concrete by Reinforcement

1. Not reinforced.

2. Reinforced.

   • Conventional.

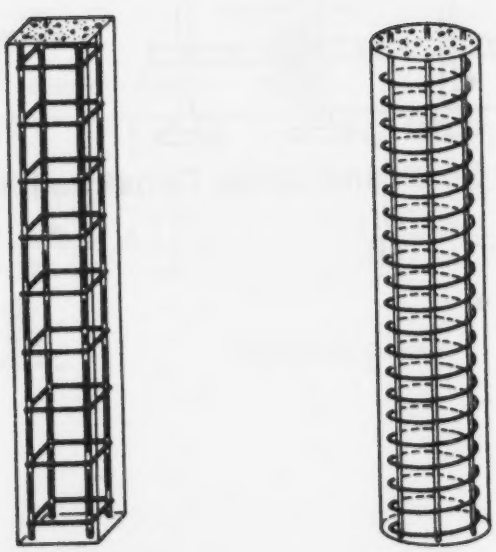
   • Prestressed.



NOTE: All of the above may be either Precast or Cast-in-Place

Concrete Reinforcement Methods

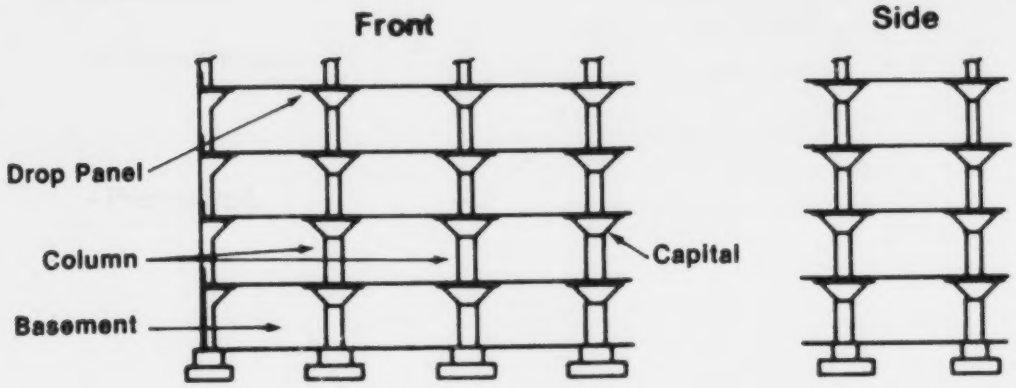
3. Conventional reinforced.



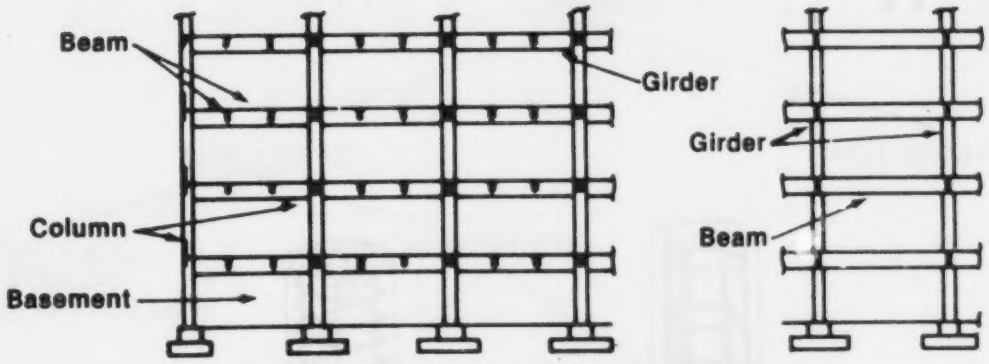
(a) Ties (b) Spiral

Reinforcement Patterns for Concrete Columns

Types of Reinforced Concrete Framing



(a) Flat Slab Construction



(b) Beam and Girder Construction

- Flat slab.

- Beam and girder.

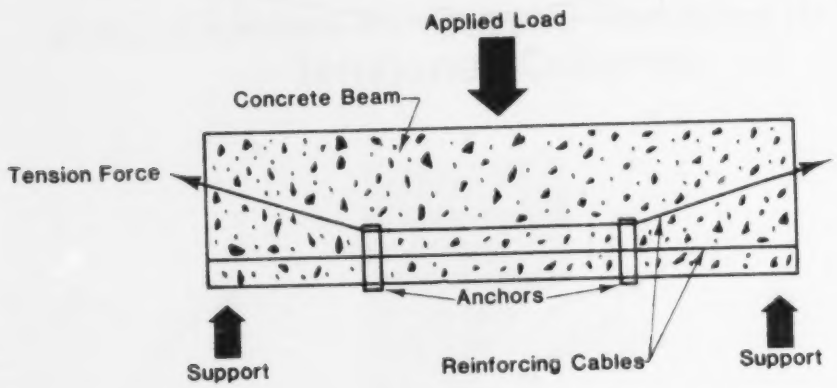
4. Prestressed.

- **Prestressed concrete:** Concrete which contains tightened high-strength steel tendons that place the concrete under enough stress to counteract the stress imposed through loading.

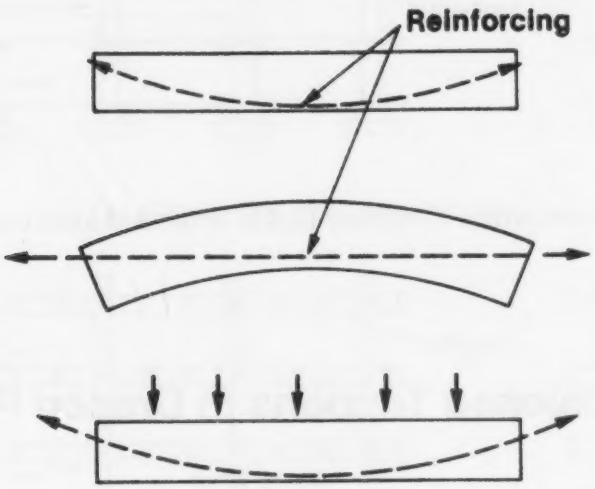
- **Pretensioned:** Concrete that is tensioned before curing.

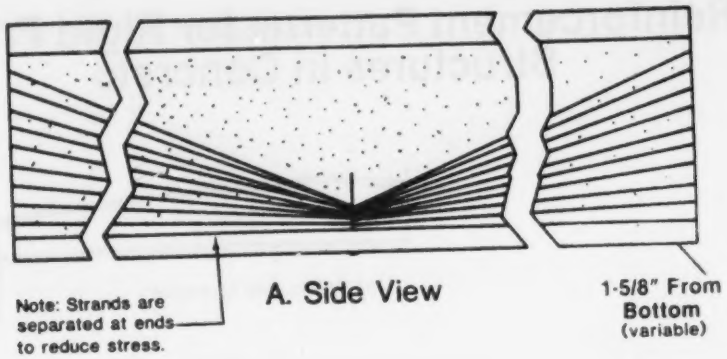
- **Post-tensioned:** Concrete that is tensioned after curing.

Pretensioned Tendons in Draped Position

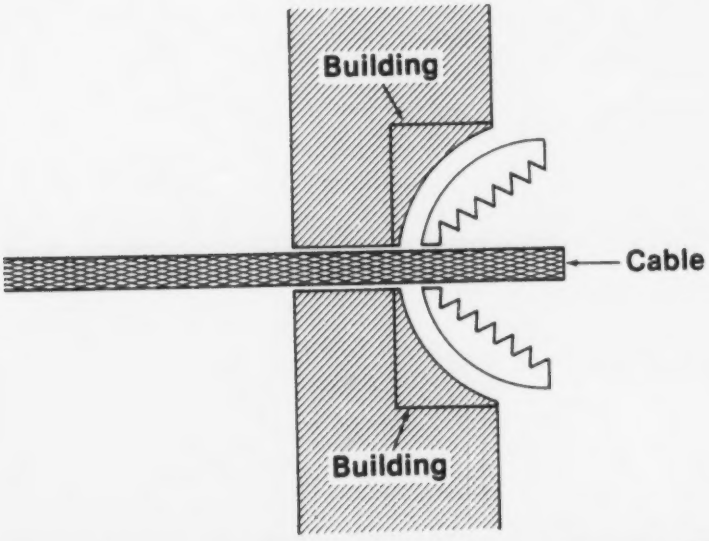


Response of Prestressed Beam to Loading



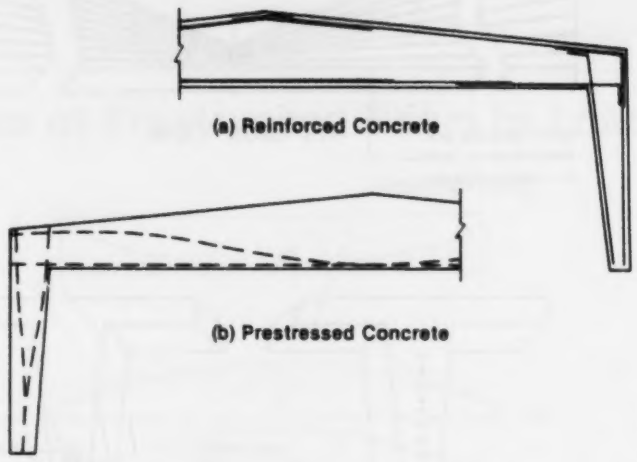

Note: Strands are separated at ends to reduce stress.
A. Side View
1-5/8" From Bottom (variable)
1-5/8 Inches Minimum Clear Space (variable)
Cables
B. Cables at Ends
C. Cables at Mid-Span

Strand Pattern for Curved Tendons in Post-Tensioned Concrete



Example of Post-Tension Clamp Cables

Reinforcement Patterns for Rigid Frame Structures in Concrete



Rigid Frame:

E. Variables in Concrete Fire Resistance

List:

CONSTRUCTION IDENTIFICATION ACTIVITY

Instructions: Briefly note construction type(s) and key observable features for the building depicted on each slide. Based on information presented so far, note any fire concerns related to that construction type or features. Note that for finished buildings, there may be more than one possible type--use the identification clues you see to make the best possible guess, but realize that it is often impossible to make a correct identification of a completed building on the basis of appearance alone.

Examples of construction types and features: steel frame (protected--specify type of protection--or unprotected); curtain wall, rigid frame, monolithic, slop-form, panel construction, tilt-up, lift slab, prestressed (pretensioned, post-tensioned).

Building 1

Construction type and features:

Fire concerns:

Building 2

Construction type and features:

Fire concerns:

Building 3

Construction type and features:

Fire concerns:

Building 4

Construction type and features:

Fire concerns:

Building 5

Construction type and features:

Fire concerns:

Building 6

Construction type and features:

Fire concerns:

Building 7

Construction type and features:

Fire concerns:

REVIEW OF FIRE CONCERNS FOR CONCRETE STRUCTURAL COMPONENTS

Symptom	Concern
Underside of concrete floor supported by steel bar joist or wood members.	Concrete is not self-supporting; may be subject to collapse as a result of failure of steel or wood.
Concrete-reinforced column with large or multiple cracks.	Heat will cause crack enlargement and spalling, exposing reinforcing rods which fail at low temperature. Also, cracks may have admitted corrosive moisture to the bars, weakening fire resistance. Serious cracks may indicate concrete weakened due to lack of moisture in curing process.
Exposed reinforcing rods in concrete column or beam.	Reinforcing rods fail at low temperature, as heat conduction affects bonding between steel and concrete. Note: Concrete beams require steel for tensile strength.
Exposed reinforcing rods in conrete--showing substantial rust.	Probable loss of adhesion of concrete to reinforcing rods due to exposure, moisture, and possibly calcium chloride admixture. Expect earlier failure.
Crazing concrete.	Not properly cured-possibly weakened, depending on extent.
Sandy, grainy texture.	Possible indication concrete was frozen at some point in curing time. Could also indicate mix low in cement. Concrete is definitely weakened.
Spalling.	May result from fire, or from alternating temperatures over period of time. Weakened concrete and reduced time to failure. Can be explosive in fire situation; hazard to eye a special concern.

Obvious cold joints.	Weak point; watch for cracking and failure there, especially on a concrete beam..
Concrete in a fire cracking, crazing, or shrinking due to water loss in heat.	Weakening-possible failure.
Precast concrete with exposed or poorly protected connections.	Connections are the weakest points. Early (serious) failure could occur as result of heat condition reducing adhesiveness and steel strength.
Curtain wall precast panels.	Usually leave voids for fire and smoke to spread to other floors around perimeter of building. If fire-stopping is supplied, examine for quality. Again, connections are critical.
Tilt-up precast concrete panels.	Welded connections must be covered-if not, early failure there may cause very serious, heavy collapse. Unprotected steel roof members often fail, and since the roof stabilizes the walls, walls are often pushed out or pulled in.
Distress cracks on beams, corbel, bearing ledgers of pilasters.	Expansion of materials due to heat will cause cracks to widen and ledger may break off. If bearing is lost, collapse could occur.
Size of concrete members.	Increased mass means greater stability.
Exposed ends of cables in prestressed concrete members, or exposed prestressed steel due to lack of concrete cover or spalling.	Heat may be absorbed and conducted through cable, which may fail at low temperature. Also, cable is under tension, reduction time to failure. Failure often quite explosive (similar to a stretched rubber band breaking).

Heavy use of concrete in structure.	Expect oven conditions-concrete holds heat for long periods.
Precast units held in place by "gravity fit."	Will not resist building movement; collapse possible under special circumstances.

Unit Three: The Principles of Fire Growth in Buildings

OBJECTIVES

Objective 1

The student will apply basic principles of fire growth analysis to assess the implications for fire growth of two trends in modern building design.

Objective 2

The student will identify and discuss fire concerns related to interior finish.

Enabling Objective 1: The student will identify key differences between field and test conditions that may alter fire performance.

Enabling Objective 2: The student will describe fire problems created by the characteristics or use of specific types of interior finish.

UNIT THREE: THE PRINCIPLES IN FIRE GROWTH IN BUILDINGS

Overview

Total Time: 2 hours, 45 minutes

A. Fire Growth Analysis in Modern Buildings
(Lecture, slides, discussion)

B. Concealed Spaces
(Discussion, slides)

C. Interior Finish and Contents
(Lecture, discussion, slides)

D. Class Review Activity: The Bank
(Table Group Activity)

UNIT THREE

Objective 1

The student will apply basic principles of fire growth analysis to assess the implications for fire growth of two trends in modern building design.

A. Fire Growth Analysis in Modern Buildings

1. Changes in building practices

- **Closed planning :** The use of fixed walls to define individual spaces.

- **Open planning:** A means of providing flexible space, by removing walls as fixed elements and replacing them with easily removable partitions.

Main Contrast Affecting Fire Growth

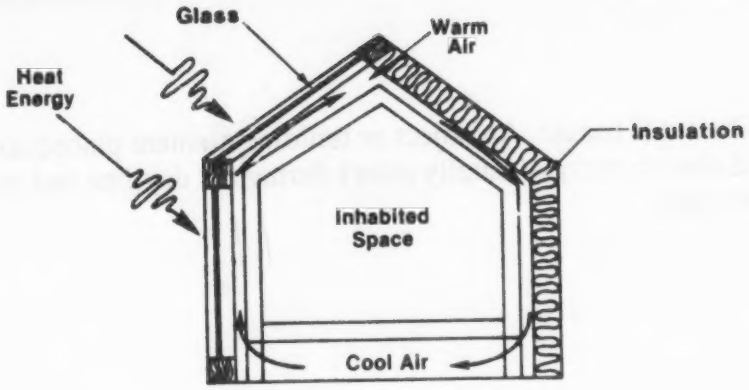
Directions: Based on thoughtful observation of the two slides typifying closed and open planning, develop a list of contrasts affecting fire growth. Also note any additional contrasts you feel would be factors in operational safety or effectiveness.

Closed Planning	Open Planning

2. Energy-conservative technology.

- **Thermal mass:** An object or building element placed so that it will absorb energy (usually solar) during the daytime and reradiate it at night.

- **Envelope structure:** A building designed as a structure within a structure in order to distribute solar energy uniformly.



Envelope Structure

Objective 2

The student will identify and discuss fire concerns related to interior finish.

Enabling Objective 1: The student will identify key differences between field and test conditions that may alter fire performance.

Enabling Objective 2: The student will describe fire problems created by the characteristics or use of specific types of interior finish.

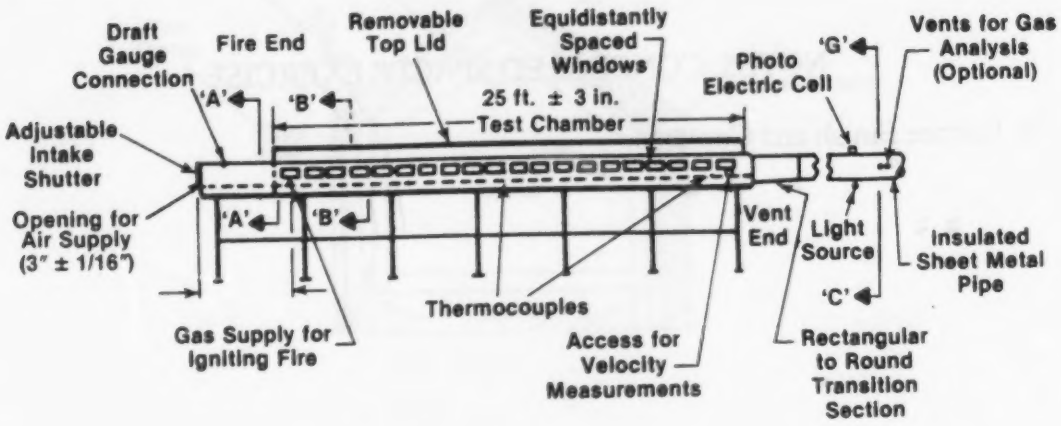
NOTES, CONCEALED SPACES EXERCISE

B. Interior Finish and Contents

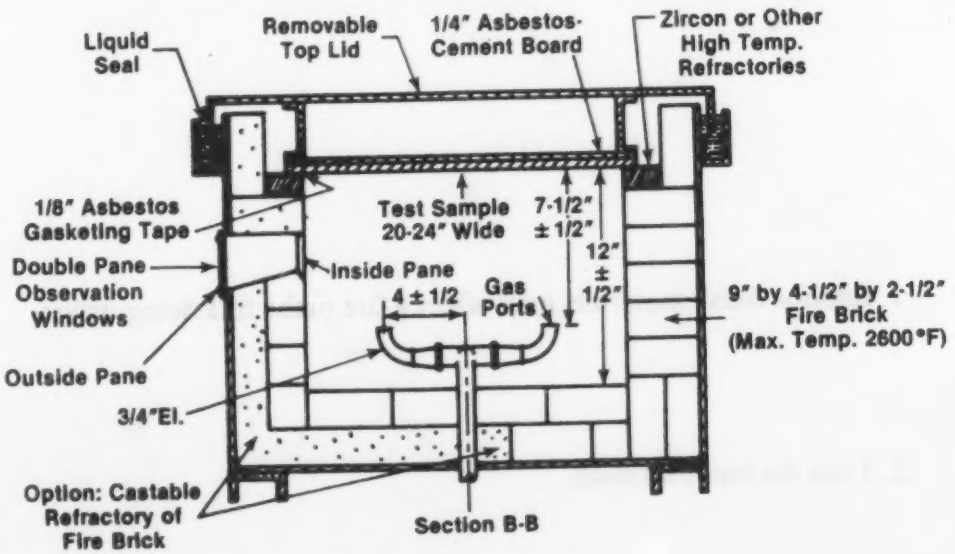
1. Interior finish materials may affect a fire in the following ways:

2. Tests for interior finish.

Test Furnace for the "Tunnel Test", ASTM E-84



(a) Longitudinal View



a. Tunnel test.

"This standard should be used to measure and describe the properties of materials, products, or assemblies in response to heat and flame under controlled laboratory conditions and should not be used to describe or appraise the fire hazard or fire risk of materials, products or assemblies under actual fire conditions. However, results of this test may be used as elements of a fire risk assessment which takes into account all of the factors which are pertinent to an assessment of the fire hazard of a particular end use." (Caution from ASTM material)

Design to measure:

b. Carpet test.

- "Pill test."

  Designed to measure:

c. Radiant Panel Test for Flooring.

Designed to measure:

3. Information collection.

4. Visual clues to problems.

5. Fireground indicators of problems.

6. Toxicity.

a. Toxic hazard: Material and environmental conditions that increase the probability that a toxic hazard will occur and an injury will result.

b. Toxic effects.

c. Testing.

d. Degree of toxicity depends on:

- Concentration.
- Exposure time.

e. Carbon monoxide.

7. Key factors in assessing toxic hazard:

a. Quantity of material present.

b. Configuration of material and compartment.

c. Proximity of other combustibles.

d. Volume of compartments of which combustion may spread.

e. Ventilation conditions.

f. Ignition and combustion properties of material(s) present.

g. Presence of ignition sources.

h. presence of fire protection systems.

i. Building occupancy.

Toxic Compounds Which May be Produced by the Combustion of Various Materials

Toxic Gas or Vapors	Concentration Dangerous for Short-Term Exposure (Parts/Million)	Source Materials	Common Forms
Dioxin, Flurans	Most poisonous synthetic chemical.	PCB (Polychlorinated biphenyl)	Viscous insulating oil in electrical transformers
Carbon dioxide, Carbon monoxide	4,000 (Carbon Monoxide)	All combustible materials containing carbon	Most common materials
Nitrogen oxides	120	Celluloid, polyurethanes	Upholstery foam/ insulating foam
Hydrogen cyanide	300 (Hydrocyanic Acid)	Wool, silk, leather, plastics containing nitrogen	Upholstery, carpeting, decorative materials
Acrolein	20	Wood, paper	Furnishings, basic building materials
Sulphur dioxide	500	Rubber Thiokols	Finish trim
Halogen acids (hydrochloric acid, hydrobromic acid, hydrofluoric acid, phosgene)	100 (Hydrofluoric Acid)	Polyvinyl chloride, neoprene, fire-retardant plastics, fluorinated plastics	Plastic plumbing, upholstery, furniture padding
Ammonia	4,000	Melamine, nylon, urea formaldehyde resins	Counter and table tops, insulating foams
Aldehydes	50 to 200	Phenol formaldehydes, wood, nylon, polyester resins	Plywood, upholstery, plastic furniture shells
Benzene	12,000	Polyvinyl chloride, polystyrene	Upholstery, cheap household platics
Tetramethyl succino-nitrile	.5*	Foamed plastics	Insulation, furniture cushions
Antimony compounds	.5 mg/m^3	Some fire-retardant plastics	Upholstery, wall covering
Isocyanates	1 (Toluene Diisocyanates)	Polyurethane Foams	Insulation, furniture cushions

*Threshold Limiting Value

REVIEW OF GENERAL BUILDING FIRE CONCERNS

Symptom	Concern
Large building or large area in building (especially with heavy fire loading).	Open spaces will allow fire to expand over large area very quickly.
Older building.	May be heavy and well-protected structurally, but probably has open stair wells and shafts. Fire and smoke may spread rapidly. Also, cracks and separations due to shrinkage or settlement may permit the spread of fire.
Breached fire walls.	Fire is spreading to other areas-may be pushed or drawn through breaching. Smoke spread also consideration.
Plastic pipe.	May melt out of walls creating a breach in the wall. "Chance of toxic gases very probable." Smoke spread potential.
Heavy fire loading.	High, prolonged temperatures which may cause even protected members to fail eventually.
Unknown amount of time for fire growth before suppression force arrives.	Could be the "safe time" inside the building has already elapsed and failure is about to occur.
Unusual environmental loading (snow, wind, earthquake). (Example: Alta, Utah, April 5, 1983 had 21 ft. of snow.)	May exceed the design "factor of safety" with only a short exposure to fire.
Unusually heavy pieces of equipment (Concentrated loads).	May exceed the design "factor of safety" with only a short exposure to fire.

Symptom	Concern
Suspended ceiling with tiles missing.	Possible exposure of suspension wires to heat of fire--wires fail at low temperature (some of aluminum material). Expected ceiling collapse.
Suspended ceiling with part in state of collapse, rest askew.	Additional tension and torsion load being applied to remaining wires--expect rest of ceiling to collapse soon.
Ducts running through beams, trusses, girders, etc., where parts of same have been removed.	Serious weakening has occurred--expect early, sudden collapse.

Class Review Activity: The Bank

Directions: On the following pages is a description of the Bank. the instructor will also show slides of the exterior of the building to orient you to the problem. Assume ignition has occured in the chair marked with an "x" near the center of the space. The fire is reported half an hour after the bank has closed. If you must make other assumptions, make them explicit. the exercise is intended to focus on the fire behavior of structural materials and the influence of interior planning, materials, and energy features on fire behavior-confine your assessment to only those questions asked below:

1. What fire conditions would you expect to find on arrival?

2. What channels of fire spread would be significant?

3. a. How will interior finish, contents, and interior configuration contribute to fire spread?

   b. Would fire spread be rapid or slow? Why?

4. a. What structural members would be damaged first?

   b. What portions might be subject to collapse?

5. What toxic products would you anticipate?

Building Description

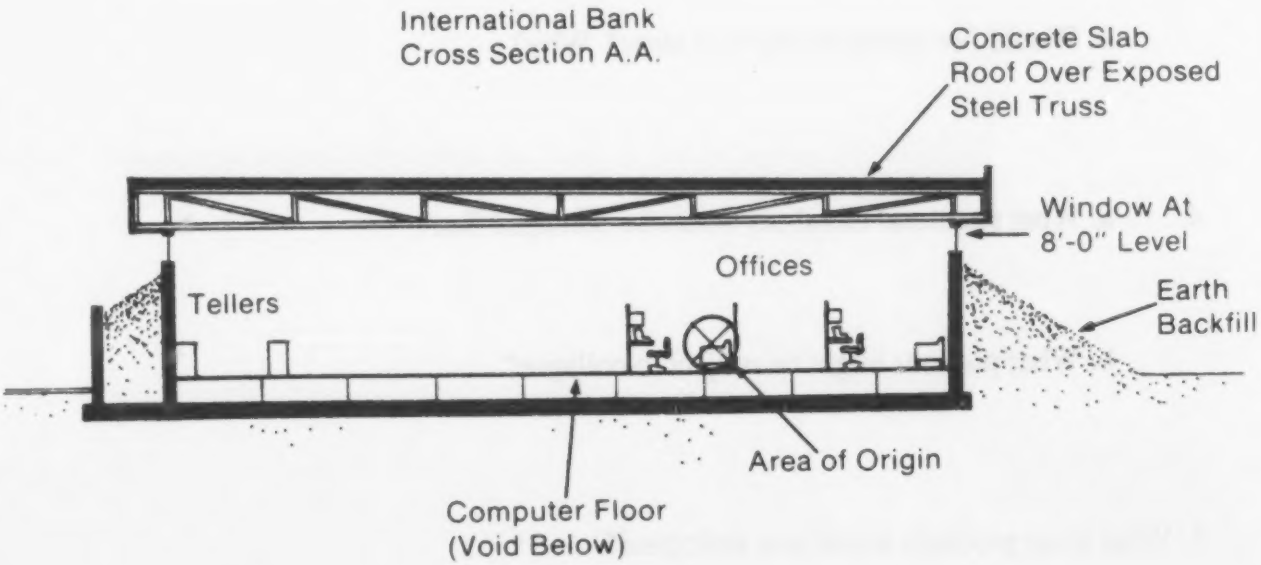
The bank's walls are earth-sheltered concrete. Two walls (north and east) are totally covered with earth. The west side is partially sheltered to allow for a drive-up teller. The south side is an 18" thick trombe wall (a concrete thermal mass, painted black, and covered with glass to capture solar energy) with no back-fill.

The bank roof and drive-through canopy are concrete slab over exposed steel trusses.

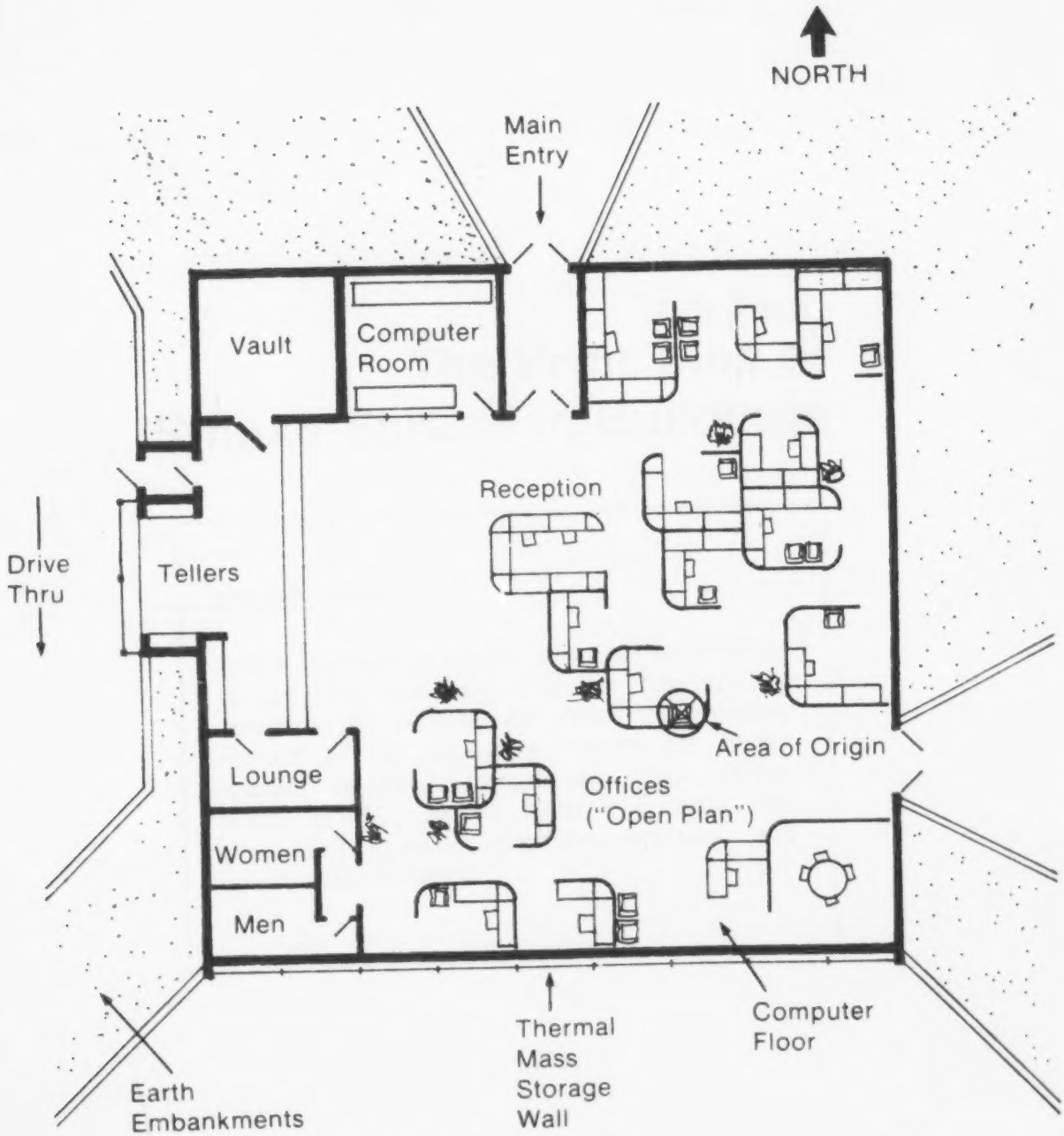
Interior Characteristics

The banking and office areas are "open plan" with few interior walls in the building. Individual work spaces are separated by free-standing 6' high partitions which are covered with polyester velour (a fleecy finished fabric) for sound control. Most chairs have a nylon upholstry similar in appearance to the wall panels. The seat cushions are highly flammable latex foam rubber. Floors are wool carpeting.

The bank's computer processing area is behind a glass wall on the north side of the building. A computer floor is used throughout the open part of the building. The computer room and vault have special fire protection systems but there is no other special fire protection.



Bank
Cross Section A.A.


NORTH
Main Entry
Vault
Computer Room
Reception
Drive Thru
Tellers
Area of Origin
Lounge
Offices ("Open Plan")
Women
Men
Thermal Mass Storage Wall
Computer Floor
Earth Embankments

Floor Plan

Unit Four:
The Principles of Smoke Spread in Buildings

OBJECTIVE

Given appropriate visual or verbal information on a given noncombustible or fire-resistant structure, the student will assess the probable impact of the following factors on smoke spread: buoyancy, expansion, stack effect, wind, HVAC, smoke control systems, fire protection systems, detection systems, and spatial characteristics.

UNIT FOUR: THE PRINCIPLES OF SMOKE SPREAD IN BUILDINGS

Overview

Total Time: 2 hours, 55 minutes

A. Analysis of Smoke Movement
(Lecture, slides, discussion)

B. Special Problems of High-Rise Structures
(Lecture)

C. Sprinklers and Smoke Movement
(Lecture)

D. The Atrium as a Special Problem
(Lecture, slides, discussion)

E. Fire and Smoke Spread in Fire-Resistive Structures
(Table Group Activity)

UNIT FOUR

Objective

Given appropriate visual or verbal information on a given noncombustible or fire-resistant structure, the student will assess the probable impact of the following factors on smoke spread: buoyancy, expansion, stack effect, wind, HVAC, smoke control systems, fire protection systems, detection systems, and spatial characteristics.

A. Analysis of Smoke Movement

1. Products of Combustion.

- **Smoke:** The airborne solid and liquid particulates and gases evolved when a material undergoes pyrolysis or combustion. (Source: ASTM, American Society for Testing of Materials.)

- **Pyrolysis:** The chemical decomposition of substances by heat.

2. Major driving forces of smoke movement.

a. **Buoyancy:** In the context of smoke movement, refers to the tendency of heated smoke to rise due to its reduced density.

b. **Expansion:** In the context of smoke movement, refers to the tendency of smoke to occupy greater volume as it heats.

- **Charles' law:** The volume of any (fire) gas varies directly with its absolute temperature. (Absolute temperature is expressed in degrees Kelvin.) Heated gas expands.

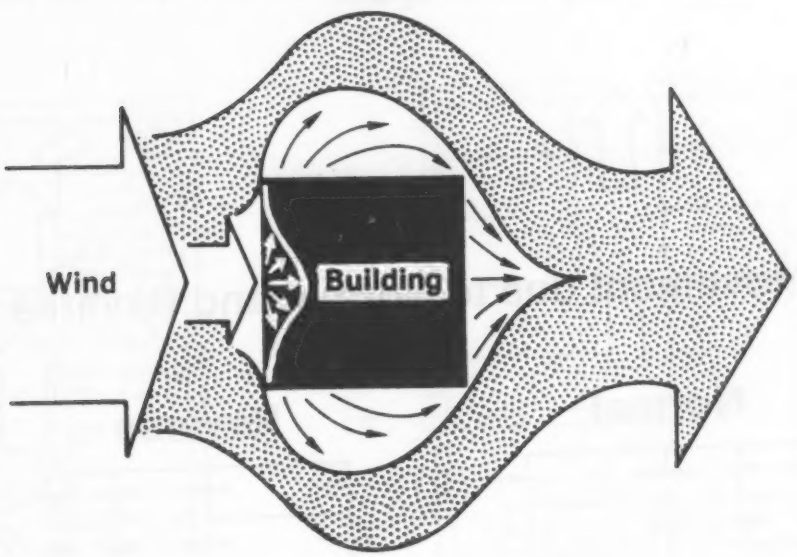
- **Boyles' law:** Where the tendency of the heated gas to expand is restricted, pressure will increase instead. Contained expanded gas increases pressure.

c. Wind

Wind pressure is:

- Positive (pushing in) on windward side.
- Negative (sucking out) on leeward side.

Wind Induced Pressure in a Building



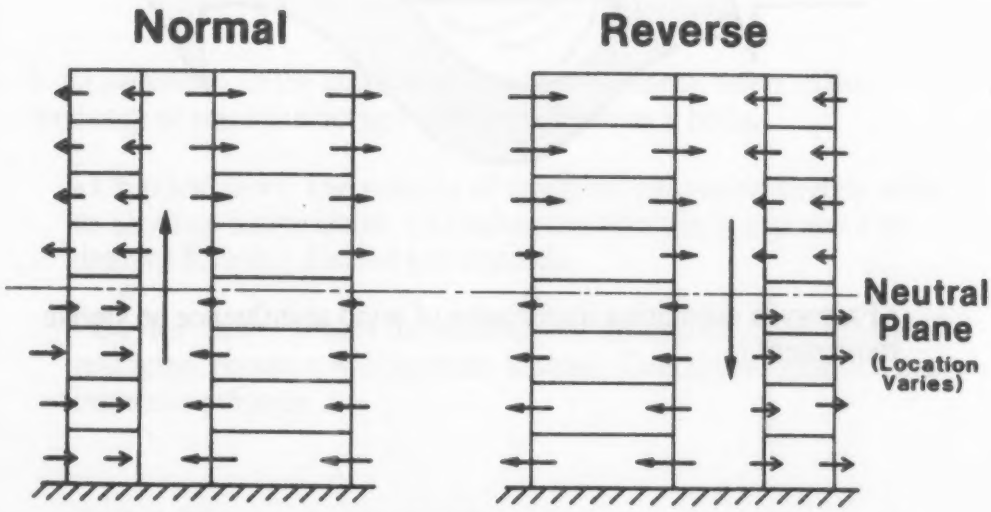
- Factors in estimating importance of wind as influence on smoke movement.

d. Stack effect.

- **Stack effect:** The tendency of air within vertical building shafts to move upward when outside temperatures are much colder than those in the building. Reverse stack effect is the tendency of air to move downward when outside temperatures are much warmer.

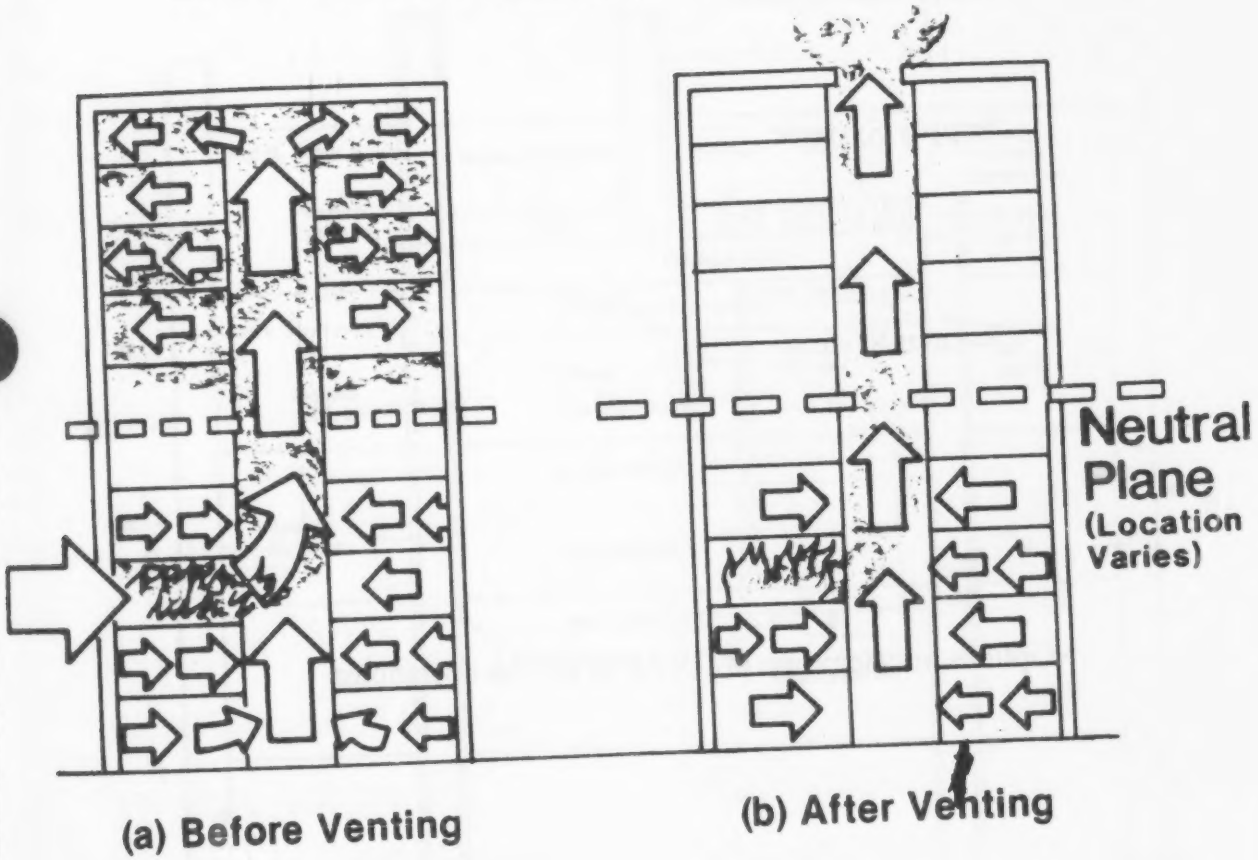
- **Neutral plane:** The elevation at which pressures inside and outside a building shaft are equal.

Air Movement due to Normal and Reverse Stack Effect.



Note: Arrows Indicate Direction of Air Movement

Effect of Top Venting with Normal Stack Effect



e. HVAC.

• **Central HVAC:** Any heating, venting, air conditioning system that supplies air to more than one floor.

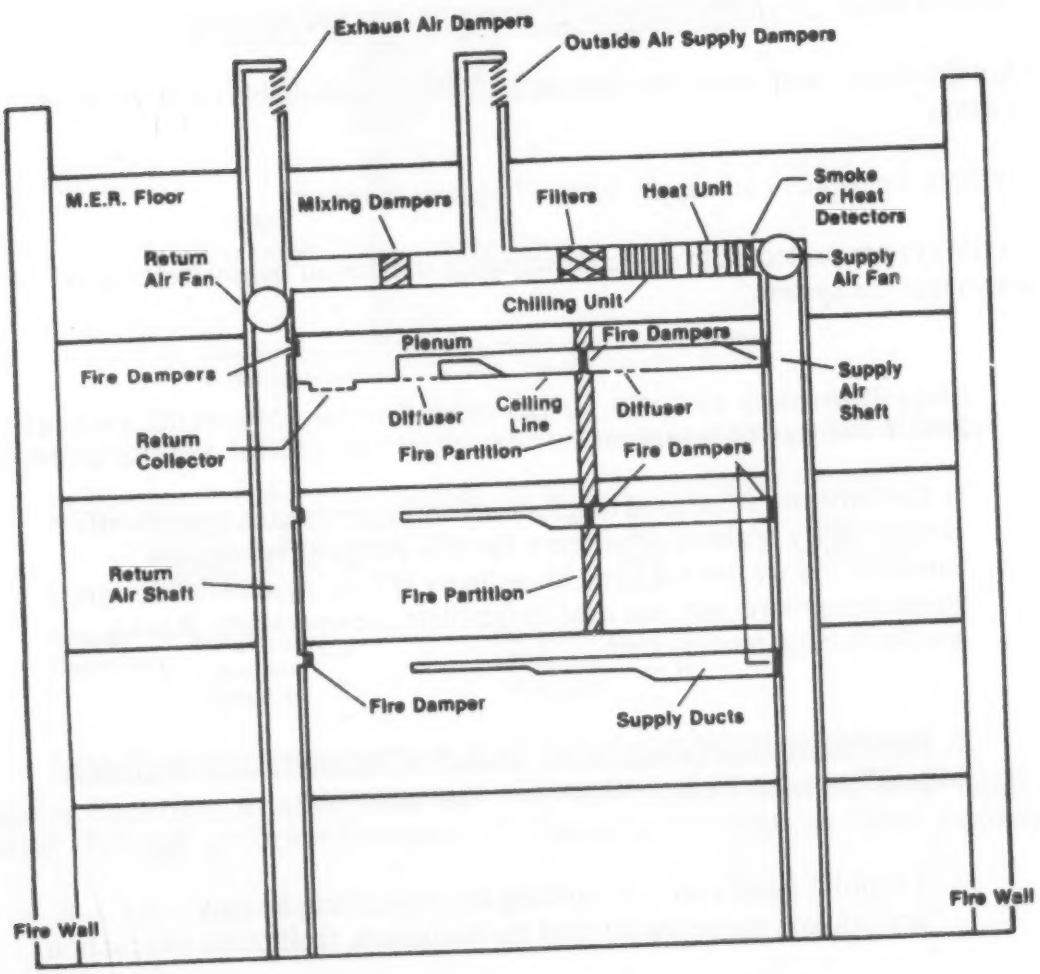
- **Processing System:**

- **Supply System:**

- **Return System:**

• Options in stategic use of HVAC to aid fire operations:

HVAC Distribution System



KEY INFORMATION NEEDS ON HVAC SYSTEMS

• Determine the location of the MER floors and the zones they serve.

• Are there any special HVAC systems in the building? (theaters, public assembly spaces, restaurants, computer rooms, stores, etc.).

• Is there a central control of the HVAC system? Where is it located?

• Determine the number of return air shafts and their location.

• Are the return air shafts common to more than one HVAC zone?

•Are the supply and return dampers on each floor controllable from a central location?

• Is there a periphery air supply system? How is it zoned?

• Is the system protected from freeze-up when outside air below freezing is drawn into the system?

3. Smoke management systems.

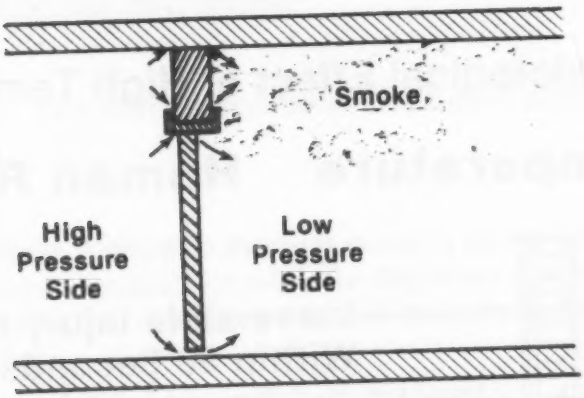
a. **Definition:** Here used to refer only to those systems **specifically designed by trained engineers for the purpose of smoke control.** As we use the term, an ordinary HVAC system not designed to aid in smoke contol but used to facilitate fire operations is not a smoke management system.

b. **Passive** smoke management: The use of the physical arrangement of building space to facilitate smoke management.

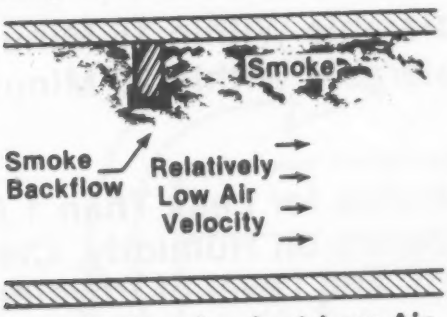
• **Smoke reservoir:** A building area where smoke may accumulate above the level of the occupants, facilitating evacuation.

c. **Active** smoke control: The use of air flows and pressure differences generated by mechanical fans to restrict smoke movement across given barriers.

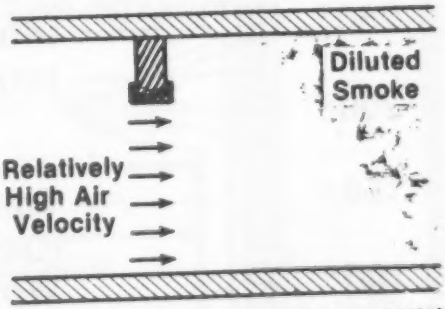
The Use of Pressure Differences to Restrict Smoke Movement



(a) Pressure Difference Across a Barrier of a Smoke Control System Preventing Smoke Infiltration to the High-Pressure Side of the Barrier



(b) Smoke Backflow Against Low Air Velocity Through an Open Doorway

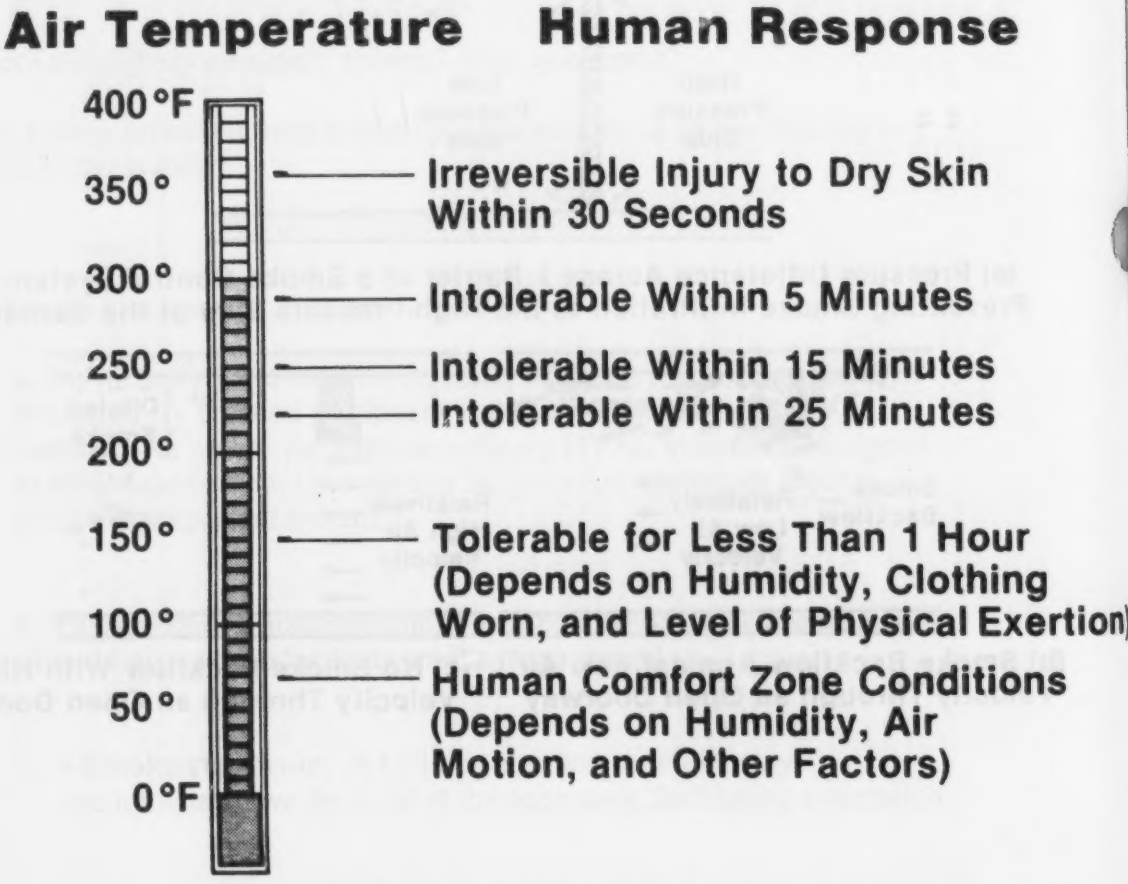


(c) No Smoke Backflow With High Air Velocity Through an Open Doorway

B. Special problems of High-Rise Structures.

1. Heat.

The Physiological Effect of High Temperature



Credit: David Egan, Concepts in Building Fire Safety

2. Communication.

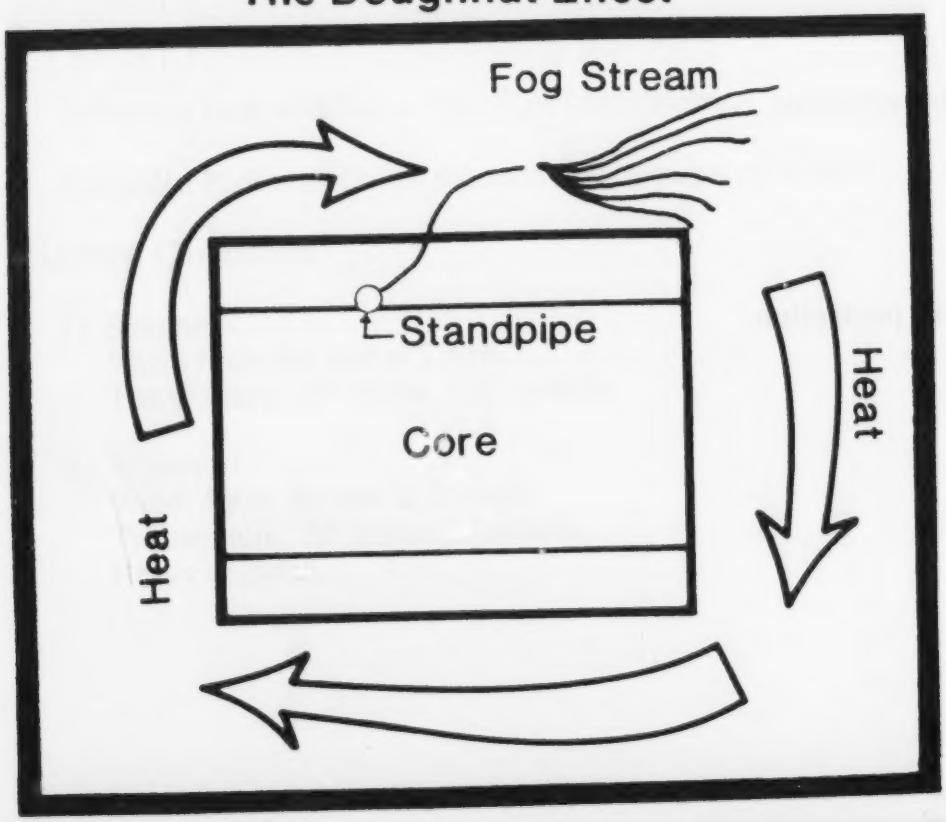
3. Elevator.

4. **Core:** An area within a multistory building where a variety of service and utility functions are clustered.

Scissor Stairs: Two stairways contained in the same core.

Doughnut effect: A situation that may occur in poorly ventilated buildings with core construction when the fog steam chases the superheated products of combustion around the core, so that they return to the firefighters.

The Doughnut Effect



READEX FICHE

C. Sprinkler and Smoke Movement

1. Activation.

2. Effect on smoke movement.

D. The Atrium as a Special Problem

1. **Atrium:** A court that pierces the floors of a multistory building and extends to the roof. In modern buildings, atriums are usually covered, often by a skylight.

2. **Fire concerns.**

3. **Fire protection.**

REVEIW ACTIVITY: FIRE AND SMOKE SPREAD IN NONCOMBUSTIBLE OR FIRE-RESISTIVE STRUCTURES

Direction: The instructor will assign your group to one or more of the fire locations and external conditions given below. For the example given, answer the following:

1. What is the probable route of fire and smoke spread through the building?

2. What factors would influence the smoke spread and life threat in the building?

Be prepared to explain your assessment to the class.

Fire Locations

Fire loactions are marked with an "x" on the plan and section views of each building.
Locations Include:

1) Bright City Mall with fire below mezzanine.

2) Gordon Park with fire on first floor near elevator.

3) Gordon Park with fire on fifteenth floor (equipment room).

External Conditions

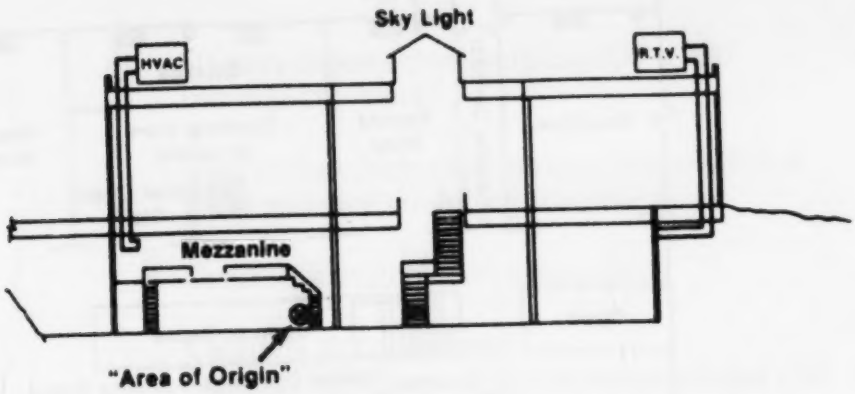
1) Summer
   Wind: From the east at 5 mph.
   Temperature: 70° inside, 100° outside.

2) Winter
   Wind: From the east at 25 mph.
   Temperature: 70° inside, 5° outside.
   Heavy snowfall.

WORKSHEET

Predictions on spread of fire and products of combustion:

SITE ONE: BRIGHT CITY MALL



Bright City Mall

Basic Structure:

Steel frame (columns & beams) with spray-on fire-resistive coating.

Floor/ceiling assembly-bar joist with concrete on metal decking. Ceiling--acoustical 2x4 lay-in tile.

Roof/ceiling assembly-build up roofing on metal deck on bar joists. Ceiling-acoustical 2x4 lay-in tile.

HVAC:

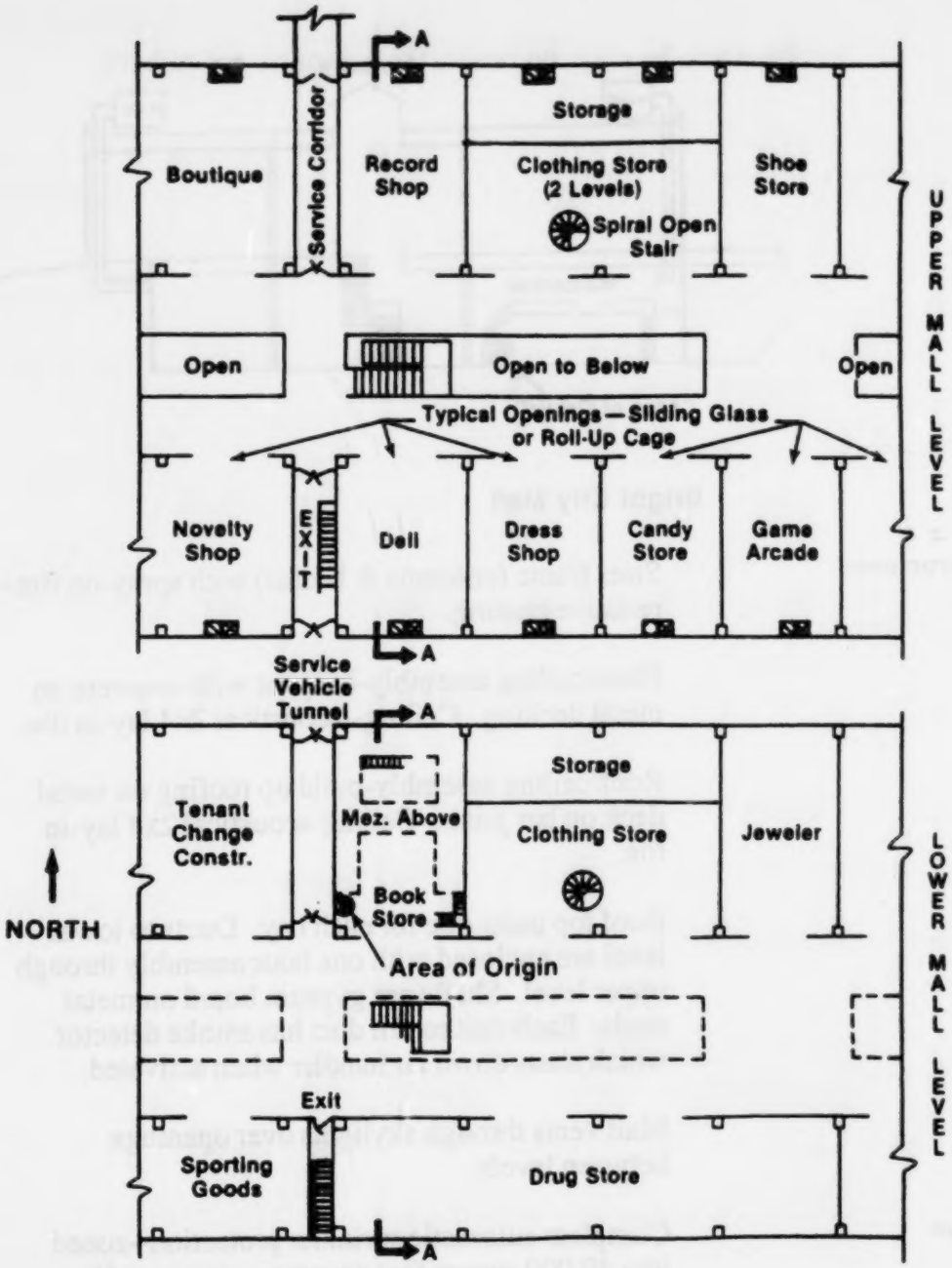
Roof top units-one for each bay. Ducts to lower level are enclosed with one hour assembly through upper level. Shafts are gypsum board on metal studs. Each unit return duct has smoke detector which shuts down air handler when activated.

Smoke:

Mall vents through skylights over openings between levels.

Protection:

Complete automatic sprinkler protection--zoned into 40,000 square feet coverage. a zone split occurs along the service/exit corridors. Sprinkler inoperative and cannot be supplied by the fire department.



Bright City Mall (Continued)

SITE TWO: GORDON PARK

Basic Structure:

30-story center atrium building 500' x 300' (average city block).

Steel frame construction on upper floors; below grade areas are reinforced concrete.

Concrete elevator/stair/utility core.

HVAC:

Centrally air conditioned.
Mechanical equipment in sub-basement and 15th floor.
Equipment rooms are unsprinklered.

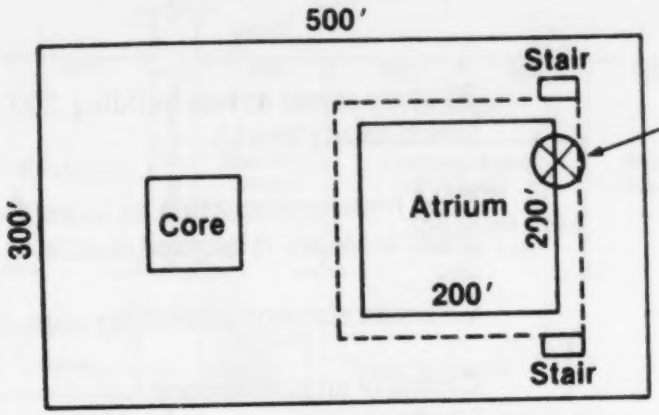
Smoke Control:

Pressurized stairways in core and near corners of atrium.

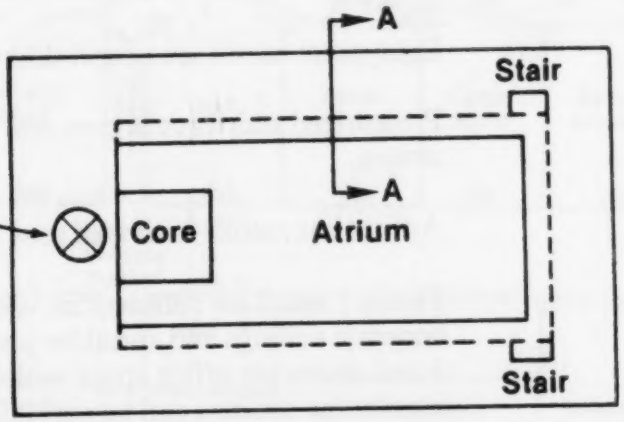
Atrium has smoke-activated roof vents.

Protection:

Floors 1 and 2 are commercial with 12 foot concrete ceilings and sprinkler protection. Floors 3 and above are office space with 8' high membrane ceilings and no sprinkler system. Offices are "Open Planned."



The Core

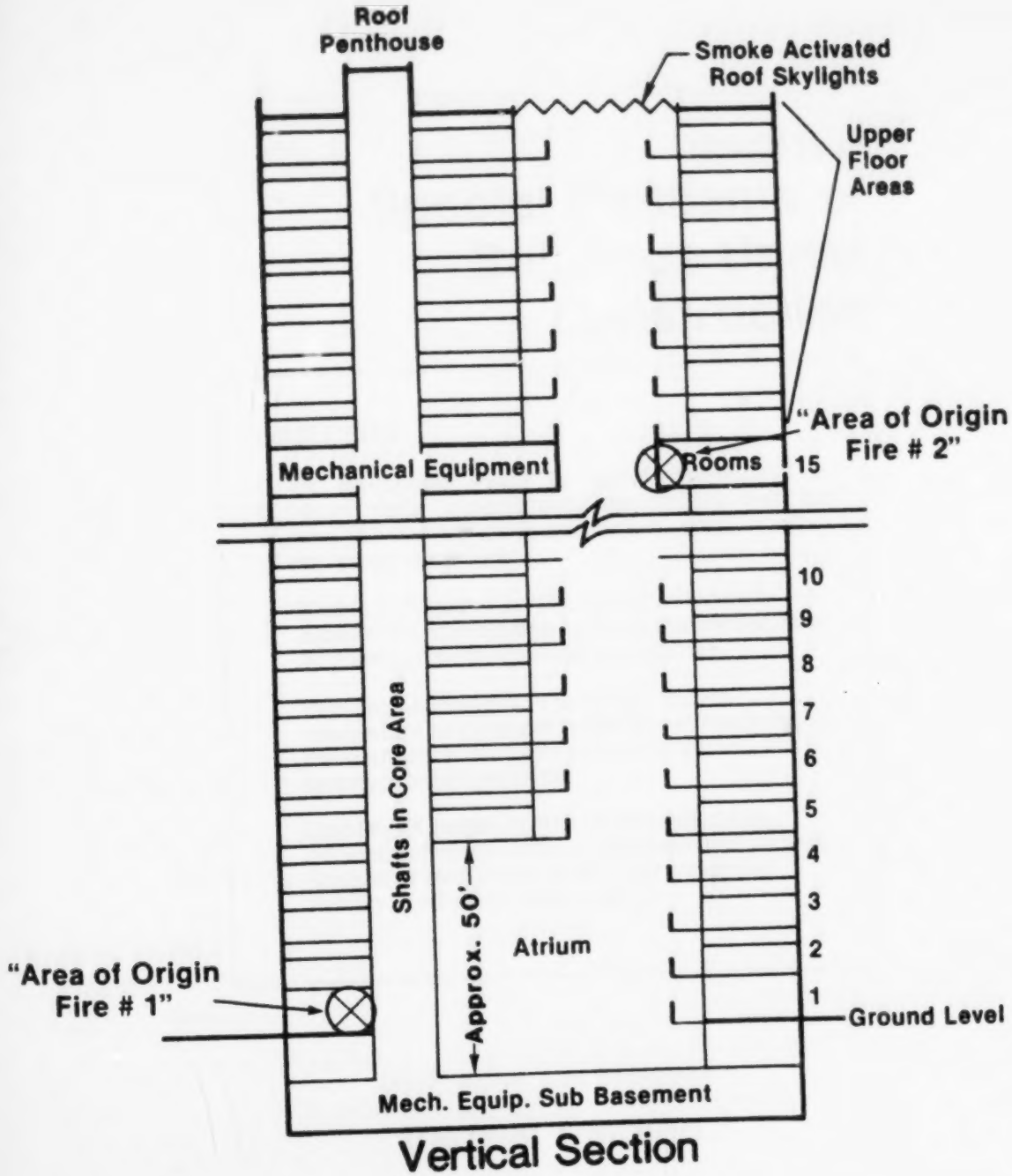


Basement Thru
4th Floors

N

Section A-A

Site Two: Gordon Park



Vertical Section

Gordon Park (Continued)

Unit Five:
Special Problems of Buildings Under Construction

OBJECTIVE

Given appropriate visual or verbal information on buildings under construction, the student will list features that may adversely affect effectiveness or safety of emergency operations.

Enabling Objective 1: The student will identify hazards and impediments to fire operations that may be present in buildings under construction.

Enabling Objective 2: The student will list combustible or explosive materials commonly found on construction sites that may cause ignition, fire spread, or safety problems.

Enabling Objective 3: The student will cite key differences between under-construction and finished concrete or steel buildings that may undermine stability or otherwise affect safety.

UNIT FIVE

Overview

Total Time: 1 hour, 35 minutes

A. Hazards and Operational Impediments
(Lecture with slides)

B. Combustible/Explosive Materials

C. Steel and Concrete Under Construction
(Lecture with slides)

HAZARD IDENTIFICATION ACTIVITY NON-FIRE AND PREVENTION DISCUSSION

D. Collapse Scenarios
(Lecture, discussion with slides)

UNIT FIVE

Objective

Given appropriate visual or verbal information on buildings under construction, the student will list features that may adversely affect effectiveness or safety of emergency operations.

Enabling Objective 1: The student will identify hazards and impediments to fire operations that may be present in buildings under construction.

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Enabling Objective 3: The student will cite key differences between under-construction and finished concrete or steel buildings that may undermine stability or otherwise affect safety.

A. Hazards and Operational Impediments

1. Exterior access.

   a. Changes as work progresses.

   b. Temporary roads.

2. Structural access.

   a. Problems may be concealed from exterior view.

b. Missing structural components.

c. Temporary structures.

d. Finish materials.

e. Application of materials.

3. Fire protection systems and water supply.

   a. Standpipe systems.

   b. Sprinkler system.

   c. Fire alarm and communications systems.

   d. Hydrants.

4. Hazards.

   a. Electrical.

   b. Inadequate lighting.

   c. Walk-offs.

   d. Tripping.

B. Combustible/Explosive Materials

1. Combustible materials.

   a. Trash.

   b. Formwork of falsework.

   c. Temporary structures.

   d. Finish materials.

   e. Other materials.

   f. Ignition sources.

   g. Complicating factors:

2. Hazardous materials and equipment.

   a. Machines.

   b. Fuel.

   c. Solvents, mastics, and finish materials.

   d. Compressed gas.

3. Explosives.

   a. Indications of presence:

   b. Determine location of explosives.

   c. Determine type of explosives used.

   d. Determine amount of explosives used.

C. Steel and Concrete Under Construction

1. Steel construction.

   a. Fire-protective coating may be omitted from lower floors until completion.

   b. Temporary connections.

2. Concrete construction.

   a. Green concrete.

   b. Falsework.

   c. Noncombustible formwork.

   d. Falsework failure and/or overpour.

   e. Post-tensioned concrete.

f. Precast concrete.

g. Excavations.

h. Cantilever platforms.

HAZARD IDENTIFICATION ACTIVITY: BUILDINGS UNDER CONSTRUCTION

Instructions

You are notified that a fire has developed in a building under construction in your jurisdiction. Your instructor will tell you which of the two buildings shown is assigned to your table. For Building 1, the fire is in the upper floors; for Building 2, it involves the lower floors. With your table group, supply as much information as you can in the following categories:

Type of construction:

Stage of construction:

Exterior access impediments:

Structural access impediments:

Status of fire protection system and/or water supply:

Combustible materials (identification and possible location):

Explosive materials (identification and possible location):

Toxic materials (identification and possible location):

Factors in structural stability:

Other hazards:

D. Non-fire Collapse Scenarios

1. Reponse to collapses under non-fire conditions.

2. Special situation.

3. Common non-fire scenarios.

NOTES ON SLIDE SCENARIOS

Appendix A

GLOSSARY

GLOSSARY

Atrium -- A covered court that pierces the floors of a multistory building and may extend to the roof. In modern buildings atriums are usually covered, often by a skylight.

Axial load -- A load that passes through the center of mass of the supporting element perpendicular to the cross section.

Balloon framing -- A wood stud framing system in which studs are continuous for full building height and inherent firestopping is not provided between floors.

Bay -- A regularly repeated spatial element in a structure composed of beams and support.

Beam -- A spanning structural member designed to carry transverse loads across a gap to a point of support with bending.

Bearing wall -- A wall that supports roofs, floors, or other walls.

Bridging -- Bracing placed between joists to stiffen them, hold them in place, and help distribute the load.

Brittle materials -- Materials that are weak in tension and shear and tend to break or fracture suddenly with little deformation.

Buckling -- Collapse of a slender element subjected to compression, in the form of sudden sideways deflection.

Built-up girders -- Beams composed of sections and designed to carry heavier loads than "rolled" beams made all in one piece.

Burning rate -- The speed with which a mass of material is burned, expressed in unit of weight per unit of time (such as pounds consumed per minute). Also known as "rate of heat release," abbreviated RHR.

Buoyancy -- In the context of smoke movement, refers to the tendency of heated smoke to rise due to its reduced density.

Cantilever -- A beam fixed at only one end.

Cast -- To place liquid concrete in a mold of the desired shape.

Cast-in-place concrete -- Concrete that is poured in the location and position where it will be used.

Central air conditioning -- A system that supplies air to more than one floor.

Checks -- Separations across the grain in wood that may occur as a result of seasoning.

Cold-drawn steel -- Steel that has been cold-worked by a method that involves pulling a bar through dies of smaller diameter to produce wire or strands. Subject to failure at relatively low temperatures.

Cold-working -- Permanently deforming a metal at low temperature, such that there is an increase in hardness and strength.

Column -- A vertical member of a structure designed to carry a compressive load in the direction of the member.

Compression -- A force that tends to push or squeeze material together.

Concentrated load -- A load applied to a relatively small area (see distributed load).

Continuous slip forming -- A rapid method of poured-in-place construction in which concrete is poured continuously as forms move upward to ensure continuous casting.

Core -- An area within a multistory building where a variety of service and utility functions are clustered.

Creep -- In reference to concrete, creep is the tendency of concrete to deform over time as a sustained load squeezes water from pores of material.

Crazed - Covered on the surface by small cracks.

Curing -- The process by which concrete hardens and obtains strength through a chemical reaction called hydration.

Dead load -- The weight of the building and any part of the building which is permanently attached or built in.

Deflection -- The bending of a beam or column because of its own weight or an imposed load.

Designed load -- A load that the building designer anticipated and planned for.

Distributed load -- A load applied relatively equally over a large area.

Ductile materials -- Materials that tend to deform before breaking or fracturing, thus giving "warning" before failure.

Eccentric load -- A load perpendicular to the cross section of the supporting element that does not pass through the center of mass.

Envelope structure -- A building designed as a structure within a structure in order to distribute solar energy uniformly.

Expansion -- In the context of smoke movement, refers to the tendency of smoke to occupy greater volume as it heats.

Factor of safety -- The ratio of the expected strength of the structure to the expected imposed forces on the structure.

Failure -- The condition of becoming incapable of a particular function. Failure of an element leads to partial or total collapse when the structure cannot redistribute the load it carries.

Falsework -- Temporary reinforcement erected to support concrete work during construction.

Fire load -- All the parts or contents of a building that are combustible, measured in British Thermal Units (BTU's) or pounds per square foot. Measure of the potential energy that may be released.

Fire resistance -- The capacity of a material or construction to withstand fire or give protection from it; characterized by its ability to confine a fire and/or continue to perform a structural function. (Same as "fire endurance.")

Fire-resistance rating -- The time in hours that a material or construction can withstand fire exposure, as determined in conformity with generally accepted standards, or from information derived from standard tests.

Fire-resistive construction -- Building construction in which the structural members (including walls, partitions, columns, floors, and roof) are of noncombustible materials that meet or exceed requirements prescribed by the applicable code.

Flashover -- A condition that results when the walls and ceiling of the fire room reach the same temperature as the fire, causing temperature to soar and flames "in a flash" to involve completely all flammable materials.

Force -- An effort such as a push, pull, or twist that tends to change the shape or state of motion of something.

Formwork -- Temporary mold erected to shape concrete.

Fracture -- A break, usually resulting in actual separation of material. A characteristic result of tension failure.

Garden apartments -- A general term for a number of different types of 2- or 3-story apartments, usually with separate apartments on each floor.

Girder -- A beam that supports other beams.

Grillage -- A series of closely spaced beams designed to carry a particularly heavy load.

Header -- A brick laid crosswise, at right angles to the length of the wall. Headers overlap two or more adjacent wythes of masonry to provide a structural bond.

Heat of combustion -- The quantity of heat released by complete combustion of one unit of mass of a material.

Heat sink -- A material that tends to absorb heat.

Heavy timber construction -- Wood construction in which the smallest dimension of a wood member is 8 inches. For a beam it is 6 inches, floor decks are 3 inches, and the roof deck is 2 inches.

Ignitability -- The ease with which a material can be set on fire.

Ignition temperature -- The temperature at which a material will continue in the process of combustion without an external source of energy.

Impact load -- A load that is in motion when it is applied (Sometimes called a dynamic load.)

Integrity -- The wholeness of a structure, especially with respect to the interaction of its elements.

Joist – One of a series of parallel beams of timber, reinforced concrete, or steel used to support floor and ceiling loads.

Lateral forces -- Forces applied sideways, such as the wind on a vertical wall surface.

Lift-slab -- A form of construction in which columns are erected to full height, and all floors cast at bottom of structure with bond breakers between them. Floors are then jacked into position.

Lintel -- A horizontal structural member over an opening such as a window or door that carries the weight of the wall above it. Lintels are generally made of steel, stone, or wood.

Live load -- Any load in the building that is not permanently attached or built in and may vary, including environmental loads.

Long-span framing – Steel framing used when long, clear spaces between supports are required. Includes trusses, girders, arches, rigid frames, and cantilevers.

Mass – The amount of material found in a given member.

Monolithic -- Literally means "one piece of stone." Used to describe concrete cast in one piece or cast with proper construction joints to ensure that the concrete behaves like one piece of stone. May refer to an entire building or one section.

Mortise and tenon joint -- A joint formed by inserting a projection from a cross section of a member into a corresponding cavity or recess in the cross section of another member.

Neutral plane – The elevation at which pressures inside and outside a building shaft are equal.

Noncombustible construction – Construction in which structural members are of noncombustible materials and assemblies, but which does not meet requirements for fire-resistive construction in the applicable code.

Noncombustible material -- A material which, in the form in which it is used and under the conditions anticipated, will not ignite, burn, support combustion, or release flammable vapors, when subjected to fire or heat.

Ordinary construction – Masonry loadbearing walls with wood-joisted floors.

Panel construction -- A form of low-rise construction in which walls are bearing, and walls and floors are joined by cast-in-place joints.

Panelized roof -- A roof composed of laminated beams, purlins, and 2 x 4 joists supporting a plywood deck covered with asphalt or tar paper. A 3-layer insulation paper stapled between beams and purlins may give off flammable gas in fire.

Passive smoke management -- The use of the physical arrangement of building space to facilitate smoke management.

Pier -- A short wide column.

Pilaster -- A supporting pillar built into the wall, either on the exterior or interior of the building.

Pinned joint -- A joint in which rotation is possible, and one member does not necessarily bend when the other does. Also called a hinge joint.

Plank and beam roof or floor systems -- A system in which wood planking or decking is laid over beams, often leaving the wood exposed.

Platform framing -- A wood stud framing system in which studs are story height and floors provide some inherent firestopping.

Plenum -- 1. The space between a suspended ceiling and the floor for the next level. 2. An air compartment or chamber to which one or more ducts are connected and which forms part of an air distribution system. (In many buildings the space between the suspended ceiling and underside of floor above is used for the collection of return air.)

Post and beam framing -- A framing system in which posts (vertical members) and beams (horizontal members) are connected by rigid joints, used with a nonbearing wall panel.

Precast -- Concrete that is cast or molded at a location other than where it is to remain. Includes not only units transported from factories, but units cast at the job site but not in their final resting place.

Prestressed concrete -- Concrete that contains tightened high-strength steel tendons that place the concrete under enough stress to counteract the stress imposed through loading. In pre-tensioned concrete the tendons are tensioned before the concrete is hardened, while in post-tensioned concrete this is done after hardening.

Purlin -- A horizontal beam in a roof at right angles to trusses and rafters.

Pyrolysis -- The chemical decomposition of substances by heat.

Reinforced concrete -- A composite material in which steel rods or cables provide tensile strength and concrete provides compressive strength.

Restrained component -- A building component installed so that it cannot move freely when heated.

Rigid frame -- A structure that uses rigid joints.

Rigid joint -- A joint in which members cannot rotate individually, and bending is transferred from member to member.

Shake -- A lengthwise separation between, not across, growth rings in wood.

Shear -- A force that tends to rend or break material by causing its molecules to slide past each other.

Sheathing -- A covering placed over the exterior studs or rafters of a building as a base for applications of other materials.

Skeleton frame -- In reference to steel structures, a framing system in which all building loads, including the walls, are supported by steel beams and columns.

Smoke -- The airborne solid and liquid particulates and gases evolved when a material undergoes pyrolysis or combustion.

Smoke control system -- The use of air flows and pressure differences generated by mechanical fans to restrict smoke movement across given barriers.

Smoke reservoir or smoke sink -- A building area where smoke may accumulate above the level of the occupants, thus facilitating evacuation.

Smoke shaft -- A vertical shaft that extends from the bottom to the top of a building and has openings at the top to the outside and openings to building spaces at each floor.

Spalling -- The flaking or fragmenting of stone or brickwork due to frost, chemical action, heat, sudden change of temperature, or moving or overloading of the building structure. In reference to concrete, spalling means the loss of surface material due to expansion of moisture when exposed to heat.

Spandrel beam -- In concrete or steel construction, a beam at the edge of the building extending from column to column, usually supporting the exterior wall.

Split --A lengthwise separation through an entire piece of wood.

Stack effect -- The tendency of air within vertical building shafts to move upward when outside temperatures are much colder than those in the building. Reverse stack effect is the tendency of air to move downward when outside temperatures are much warmer.

Static load -- A relatively unchanging load.

Stretcher -- A brick laid lengthwise along a wall.

Surface texture -- The visible surface form of a material.

Suspended load -- A load that is held in place by attachment of something above it.

Tension -- A force that tends to pull material apart.

Thermal inertia -- A measure of the tendency for heat to collect on the surface of a material.

Thermal mass -- An object or building element placed so that it will absorb energy (usually solar) during the daytime and reradiate it at night.

Toe nail -- To drive a nail on an angle through one member and into another.

Tongue and groove joint -- A joint formed by inserting a projecting part of a member--either a continuous ridge or shorter projection--into a corresponding opening or groove.

Torsional load -- A load parallel to the cross section of the supporting member which does not pass through the long axis.

Trombe wall -- An exterior glazed wall separated from an interior thermal mass.

Truss -- A framework of members that attains stability through triangular formations.

Undesigned load -- A load that the building designer did not anticipate and plan for.

Wall bearing structure -- A building in which the walls support roof and floors, and are not dependent on a skeleton frame to support themselves.

Wane -- The presence of bark or absence of wood at the corner of a piece of lumber.

Wythe -- A continuous vertical section of masonry one unit in thickness.

APPENDIX B
Reference Articles

Vincent Dunn, "Parapet Walls .... and their Collapse", WYNF (1978) B-1

Bruce Varner, "3 Firemen Hurt as Canopy Collapses", Fire Engineering, (November, 1971) B-7

Dick Sylvia, "Dangers of Steel Bar Joists and Noncombustible Buildings", Fire Engineering B-10

Dick Sylvia, "Noncombustible Buildings - Death Traps for Firefighters", Fire Engineering B-12

John Mittendorf, "Lightweight Construction", Western Fire Journal, (January, 1982) B-14

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John Mittendorf, "The Built-In Hazards of Roof Construction", Western Fire Journal, (July, 1981) B-31

Francis Cruthers, "Recognizing the Probability of Building Collapse", Fire Engineering, (February, 1975) B-36

Jerry Laughlin, "Planning Helps a Fire Department Cope With Chaos of Building Collapse", Fire Engineering, (November, 1981) B-43

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NFPA Fire Record Department, "Collapse of the Hotel Vendome", Fire Journal, (January, 1973) B-58

Bernard Erlin and William Hime, "Chloride-Induced Corrosion", Concrete International, (September, 1985) B-64

PARAPET WALLS...and their collapse

Excerpted from WYNF (Fourth issue, 1978)

by Vincent Dunn
Deputy Chief • 7th Division

Collapse: 1. *to fall or cave in; crumble suddenly*. That is the first definition of the word collapse as found in the Random House dictionary. To that definition should be added: *an occurrence most dreaded by firefighters.*

Although a collapse can manifest itself in many ways, the collapse of a parapet wall, often bringing the entire front of a building with it, is a particularly dangerous one. In recent years, collapses of parapet walls have been encountered with alarming frequency.

What is a parapet wall? Why do they collapse so frequently? What actions can be taken at fires, prior to their collapse, that will prevent the possibility of a firefighter being seriously injured or killed?

To answer these questions, the author of this article, a Deputy Chief of Department and veteran New York City firefighter for 21 years, delves into the problems and peculiarities of parapet walls.

On November 26, 1977, a second alarm fire raged out of control in a row of stores housed in an N.F.P., 125' x 100', one story, commercial structure, located at 141 to 151 Dyckman Street, in the Inwood section of Manhattan.

Thirty-four minutes after the initial alarm was transmitted, the 19th Battalion made a visual survey of the fire building's front wall, and discovered a bulge in a small section of the parapet wall, approximately 50' from the Exposure #2 side. Upon receiving the report of this condition, the 7th Division ordered a change in firefighting tactics from interior to exterior attack. Companies operating hoselines at the front of the fire building were directed to take positions in the roadway between parked cars. Firefighters were not permitted to operate on the sidewalk in front of, or near, the collapse zone. (The collapse zone is the expected ground area a falling wall will cover when it collapses. It is at least the distance away from the wall which is equal to the height of the wall. In many cases, heavy stones will fall further than this distance.)

As the closely watched bulge became greater, it was expected that this portion of the front wall would fall to the sidewalk. Approximately thirty-five minutes after the bulge was discovered, the entire 125' of stone parapet wall crashed onto the ground in one wave. The fifteen foot wide sidewalk was covered with two to four feet of crumpled ornamental stone, bricks, advertisement signs, and twisted metal.

PARAPET WALLS

A parapet wall is defined by the New York City building code as the continuation of an exterior wall, fire wall, or party wall, above the roof line. The parapet section of exterior walls may, or may not, extend around the entire perimeter of a building roof area.

Parapet walls are found on many types of buildings; however, the most serious collapse potential of parapet walls exists from the front parapet wall found in one story commercial buildings. These front walls are sometimes called the facade of the building.

WALL STABILITY

Walls receive much of their support and strength from the load they support, and from other portions of the structure to which they are connected. The more floors a wall supports, the more stable the wall. There is a mutual support arrangement between the wall and the floor beams. For this reason, a bearing wall, which carries a load of some part of the structure in addition to its own weight, is inherently more stable than a non-bearing wall which supports no additional weight and is simply connected to the structure by braces. Less stable than either the bearing or non-bearing wall, is the free-

standing wall. A free-standing wall neither supports nor connects anything. The higher that a free-standing wall is built, the less stable it becomes. A lateral load applied to a free-standing wall, such as a wind, or ladder placed against its top, can cause it to topple.

A parapet wall is sometimes constructed as a free-standing wall; the upper portion being strictly ornamental. It neither supports a portion of the structure, which in turn could return some stability, nor is it interconnected at the top to other structural parts of the building. It is, as the term implies, just "standing" on the roof of the building. The instability of parapet walls, at other than fire situations, is often dramatized in newspaper articles telling of these walls being blown down by high winds; sometimes injuring a person, or causing damage to an occupancy below.

DYCKMAN STREET COLLAPSE

Three factors led to the collapse at the previously mentioned Dyckman Street fire.

- Heat from the fire expanded an "I" beam, which caused the parapet wall to bulge out.
- Heavy stone ornamental corbelling at the top of the wall, and the manner in which it was tied together, caused the entire wall to fall instead of only the weakened section.
- The parapet wall was attached to the building at the lower portion only. In effect, the parapet wall was free-standing.

The fire, which had burned for some time, heated an "I" beam which ran the depth of the fire building. This heated beam expanded lengthwise, pushing another "I" beam which ran across the width of the stores at the front of the building. This second "I" beam supported the brick and stone parapet wall. When it was pushed out of place by the heated "I" beam, it took the brick parapet wall with it, causing a small bulge. The ornamental stone corbelling, which extended for twelve inches from the face of the wall at the top portion, further increased the wall's instability.

These conditions caused the wall to become top heavy and created a cantilever effect at the upper portion. When the wall fell, both of these influences were exhibited; the wall making a complete somersault before striking the ground. This was verified by the intact portions of the wall as they lay on the sidewalk.

Parapet Wall Reinforcement. The parapet wall was reinforced and tied together with metal angle irons and rods. This reinforcement was accomplished by connecting the entire length of the wall with 2-1/2" angle irons at the top of the wall behind the brick backing. The height of the wall was fastened by reinforcement rods. Unfortunately, the rods were not connected to any portion of the building; they simply held the wall together. The stone corbelling, at the top of the wall, was fastened to the lengthwise 2-1/2" angle irons by 1-1/2" angle irons. The method of attaching this entire wall to the structure consisted merely of 1" metal connecting strips securing the base of the wall to the roof beams at ten foot intervals. The wall was actually free-standing. (Pic2)

PARAPET WALL COLLAPSES IN THE BRONX

The Borough of the Bronx is an area that contains many one story commercial buildings with parapet walls. These structures house small manufacturing firms, garage and trucking companies, and retail stores. When driving an automobile through this borough, a casual glance at some of the front parapet walls of the one story structures, reveals a serious problem. Some of these parapet walls lean in, or out, from the building line, indicating a weakened condition. Others have sections of brickwork or coping missing. Heavy advertising signs extend out over sidewalks, fastened to masonry walls by rust covered metal bracing. There are still some front walls holding up canopies and marquees; the causes of many past parapet wall collapses.

Third Avenue Collapse. The New York City Fire Department's experience with collapsing parapet walls of one story commercial buildings has been a long and deadly one. The worst parapet wall collapse occurred on April 4, 1956, at 4085 Third Avenue, Bronx, N.Y. While companies were operating cellar pipes and handlines at the front of a one story furniture store, the entire 100 foot front wall collapsed, killing six men. The front of this building supported a marquee; the building being formerly occupied as a theater. The marquee was not removed after the change in occupancy. The weight of this marquee was determined to be

the cause of the wall failure. Some of the victims, however, were not under the marquee, but were operating well to one side of it. This parapet wall, like the one at the Dyckman Street fire, was tied together with metal reinforcements. And when it fell, it fell in one piece.

Jerome Avenue Collapse. On October 4, 1965, at 2744 Jerome Avenue, Bronx, N.Y., while operating at a third alarm fire in a vacant one story food store, four men were injured (one seriously) when struck by heavy masonry bricks from a falling parapet wall.

Bronx Street Collapse. The most dramatic photographs of a parapet wall collapse of a one story commercial building were taken on May 27, 1968.

These N.Y. Daily News photos show the wall before it collapsed, as it was collapsing, and, finally, the bulk of twisted steel and brick as it lay in the street. A study of these photographs tells us much about wall collapse. The photo taken prior to the collapse (Photo A) reveals the parapet wall to be free-standing. It is cantilevered with respect to the wind load, the weight of the "garage" sign, and any ladders placed against it. The wall top appears to have ornamental cast stone corbelling. This corbelling can cause a wall to lean outward. Approximately fifteen minutes after arrival of this Department, the wall collapsed.

The photo taken as the wall collapsed illustrates several factors about parapet wall failure. First, the sheer mass of the falling wall. Second, when front parapet walls collapse, it is not just the upper portion extending above the roof that falls; the entire masonry facade comes with it. In this case, the free-standing parapet was only three feet high, yet the entire eight or ten foot high front brick wall over the window openings also fell.

The most important fact revealed in this photo is that the reacting men could not have escaped the falling wall, had they been beneath it. These men are alive today, not because of their quick response to the danger, but because they were outside the collapse zone. Had they not reacted to the falling wall, and maintained their position, they would have survived; possibly being hit by several rolling bricks. However, if they had been within the collapse zone, and attempted to escape, they probably would not have been fast enough. Re-examining both these photos shows that the firefighter stretching the hoseline and the supervising officer are not within the property line of the fire building at the time of the collapse. The men operating the heavy calibre stream are positioned outside the collapse zone, and are effectively utilizing the reach of their stream. (Hose stream reach should always be used to advantage, allowing companies to position themselves away from unsafe floors, ceilings, or walls.)

The third photo, taken after the collapse, reveals some important factors about parapet wall collapses. First, the failure of one section of a wall will bring down an entire building frontage. While Photo B shows that the section with the heavy sign was first to collapse, Photo C clearly indicates that the entire wall did, in fact, crumple to the street. If any firefighters were beneath that parapet wall, even some distance away from the sign, they would have been in the same danger as if operating directly beneath the sign. Second, firefighters operating on a sidewalk in front of a one story building that has a parapet wall collapse, invite serious injury; possibly death. *The sidewalk is always within the collapse zone of one story structures.*

Finally, it has been sometimes felt that a person could escape a falling front wall by stepping into the doorway as the wall falls out. Photo C shows this to be untrue. Anyone inside this structure would have suffered the same fate as anyone on the sidewalk.

RESPONSIBILITIES

All officers operating at a fire have the overall responsibility for safeguarding the men under their command. When the potential for a collapse exists, there are specific responsibilities at each level of command. These specific responsibilities vary slightly for chiefs, and company officers; yet when each supports this obligation, the results are an overall safe operation. It is to ensure a safe operation, during potential collapse situations that the following recommendations are made.

• The officer in overall command of a fire is responsible to act promptly when any condition of a collapse potential is reported to him. Canopies, marquees, heavy

overhanging advertisement signs, and stone corbelling must be considered carefully when evaluating a wall's stability. Any indication of a wall failure, such as a bulge or crack, discovered by an officer, or reported to him by a member, must result in a compensatory reaction by the officer in command.

One of the most difficult decisions that a chief officer is charged with is the responsibility of determining the boundary between stability and collapse during a fire; sometimes occurring in the dark of night, when smoke hampers visibility, and there is a rapid spread of the fire. Actually, this is his number one priority at fires in structures where all persons have been evacuated or which are unoccupied.

• Chief and company officers are charged with the responsibility of reporting, to the officer in command, any dangerous condition in their area of operations which could lead to the failure of a portion of the fire building. At the same time, the sector officer must take immediate steps to counter the problem. The officer in overall command of the fire, in turn, should notify all other sectors of this reported danger (units operating at distant locations may possibly be reassigned to the danger area, and must be made aware of the collapse potential.)

• Company officers are responsible to supervise closely the men in their units, and prevent them from entering a designated collapse zone. Once members are ordered to operate away from a wall that is in danger of collapse, the company officer is responsible to provide continued enforcement of that order.

• When operating at a fire where precautionary restraints are necessary, company members must comply with the orders of their officers.

CONCLUSION

Experience has shown that well-intentioned, but ineffective and uncontrolled action is the number one problem at a crisis situation prior to, or immediately after, a building collapse. It is recognized that the training and general policy of this Department directs its members to operate as a unit in a forward-moving, offensive, attacking manner, and changing that in-breeding at an uncontrolled fire requires the highest discipline. However, discipline, as we all know, is the mark of a professional firefighter.

At the Dyckman Street fire, injury to personnel was successfully avoided because all members lived up to their responsibilities. The 19th Battalion reported sighting the bulge in the parapet wall to the officer in command; the officer in command then ordered units out of the fire building, and set up a collapse zone. Company officers and members maintained the required safe distance. When the wall suddenly fell, there was no one in the collapse zone.

The collapse at the Dyckman Street fire has taught us much. The lessons learned make it incumbent upon every member of this Department-chief officer, company officer, and firefighter alike-to display the responsibility and discipline that was shown at this fire, in order to ensure that future operations of this nature are as safe and as injury free as possible.

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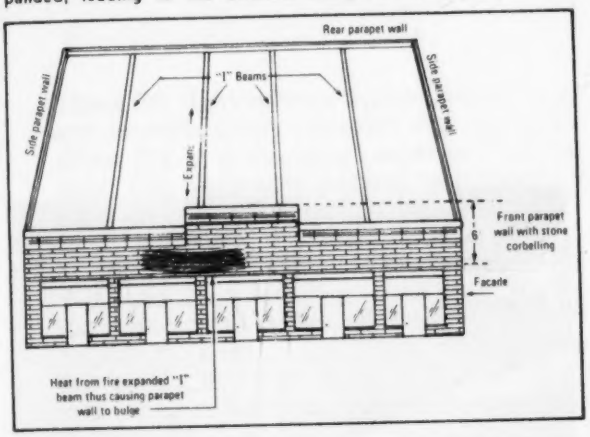
Illustration below shows layout of the fire building, with "I" beam construction. As the "I" beams were heated by the fire they expanded, leading to the eventual collapse of the parapet wall.



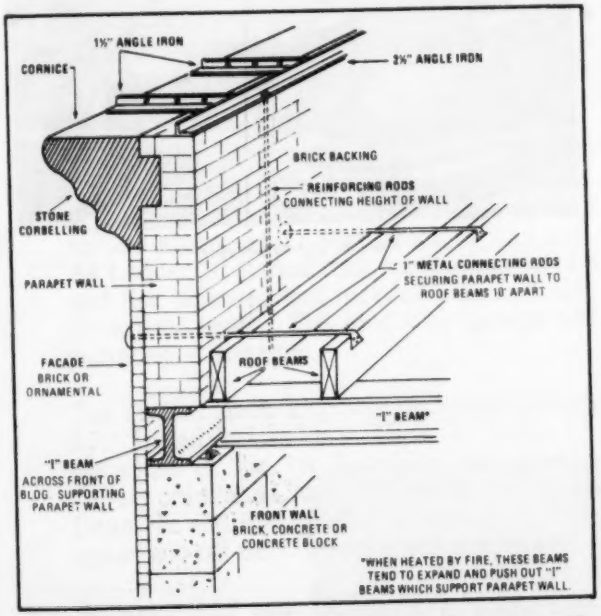


Illustration above shows typical construction of parapet walls. Parapet walls throughout New York City are built in a like manner. Construction similar to the above was used at Dyckman Street.

Above: Arrow Furniture store just prior to "grand opening." This building was formerly occupied as a theater (note marquee). Below: After fire and collapse which killed six firefighters. Fire occurred on April 4, 1956 at 4085 Third Ave. in the Bronx.

Debris covers Dyckman St. after collapse. Bricks, concrete, and twisted steel filled the street to a height of four feet. Anyone operating in the collapse zone would surely have been killed.

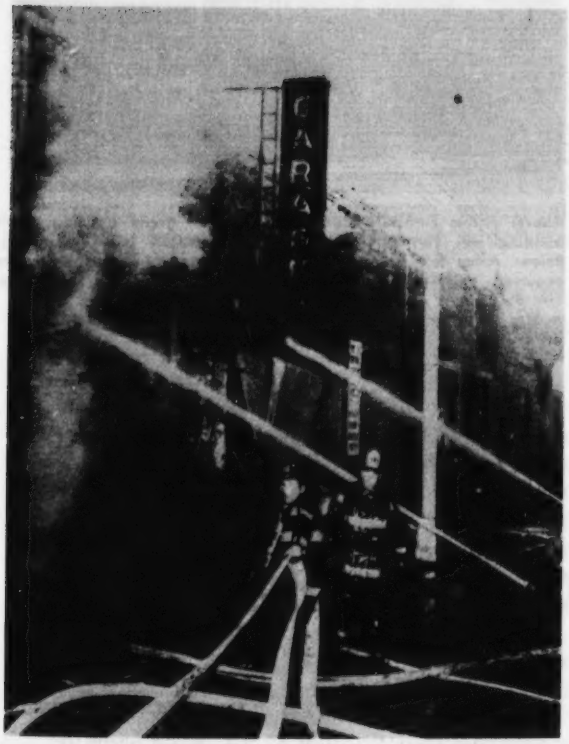


Photo A: Firefighters stretch handlines and men heavy calibre streams shortly before collapse at 2070 Bronx St. on May 27, 1968.

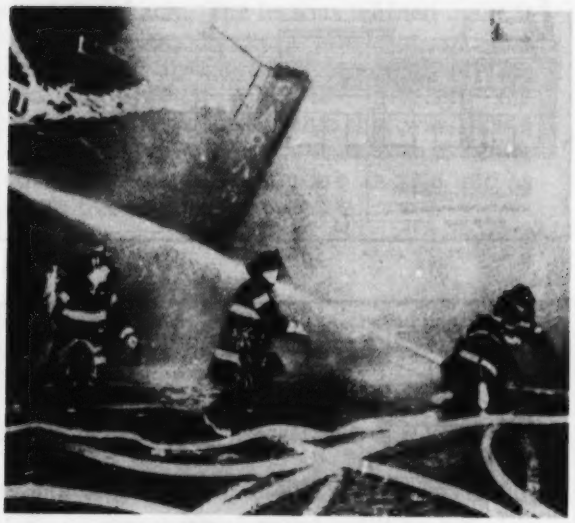


Photo B: During collapse.

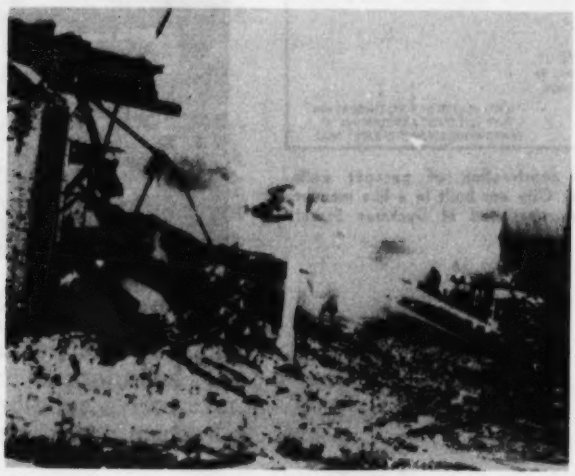


Photo C: After collapse.

3 Firemen Hurt as Canopy Collapses

2-Alarm blaze spreads through cockpit and open fire door

Excerpted from Fire Engineering, November 1971

By: Bruce Varner

Three fire fighters were injured when a wall and a metal canopy collapsed during a three-alarm fire in a shopping center in Phoenix, Ariz. Fire walls were credited with making it possible for fire fighters to contain the blaze.

The blaze, which started in the Paddock Pool and Patio Shop, apparently had been burning for some time before it was noticed by neighbors across the street, according to Battalion Chief Paul Carr. The first alarm was struck at 9:07 a.m. last December 9, and Engines 20, 7, and 9, Ladder 20, Hose 9 and the chief of the 4th Battalion responded. The apparatus from Station 20, a mile away, were the first to arrive at the Bayless Shopping Center, at Seventh Street and Glendale Avenue, at 9:10 a.m.

Engine 20 reported considerable smoke issuing from a roof vent over Paddock Pool, and the captain of Ladder 20 radioed for a second alarm, which was struck at 9:11 a.m. As Ladder 20 started roof ventilation, smoke and fire billowed and receded intermittently from roof vents. The roof was spongy and pulsating at that time.

The second alarm response included Engines 17, 5, and 2, Ladder 9, Hose 3, Utility 13, the chief of the 1st Battalion, the on-duty deputy chief and Chief of Department Harold Dean. In addition, the fire marshal, the arson squad and off-duty deputy chiefs responded.

Between 9:15 and 9:17, a back draft in the cockloft over Paddock Pool caused the ceiling to collapse and blew out plate glass windows. The fire then dropped to the floor level and spread throughout the Paddock Pool area. At the same time, the fire vented itself through the roof and also spread through the undivided cockloft from the fire wall in the Paddock Pool store near Paddock's Casual World store to the fire wall across a breezeway at the fire side of the Studio of Hair Design, which received heavy smoke damage but no fire damage.

Fire fighters reported that a fire door in the Paddock Pool fire wall was blocked open by stock stacked against and in front of it. The result was total loss of the Casual World stock as a result of smoke, heat and water damage. Nevertheless, the fire fighters were able to confine the fire at this wall.

As Battalion Chief Ted Cummings said, "If it hadn't been for those walls, we would probably have lost the entire shopping center."

Canopy collapses

The cantilevered canopy across the fronts of Paddock Pool, Marney's Liquor Store and two other stores in between collapsed about 9:50 a.m., bringing down with it part of the wall.

Fire Fighter Leroy Raebel recalled, "Captain (Don) Massetto and I were just inside the door of the liquor store. The ceiling was burning and we were trying to hose it down. We were just changing from a 2-1/2-inch hose to a 1-1/2-inch line to give us a little more maneuverability when everything fell in. We scrambled out of there as fast as we could."

Raebel, Massetto and Fire Fighter Pete Avila were getting out when the canopy swung down and hurled them against the store front. Fortunately, they were able to escape with minor injuries.

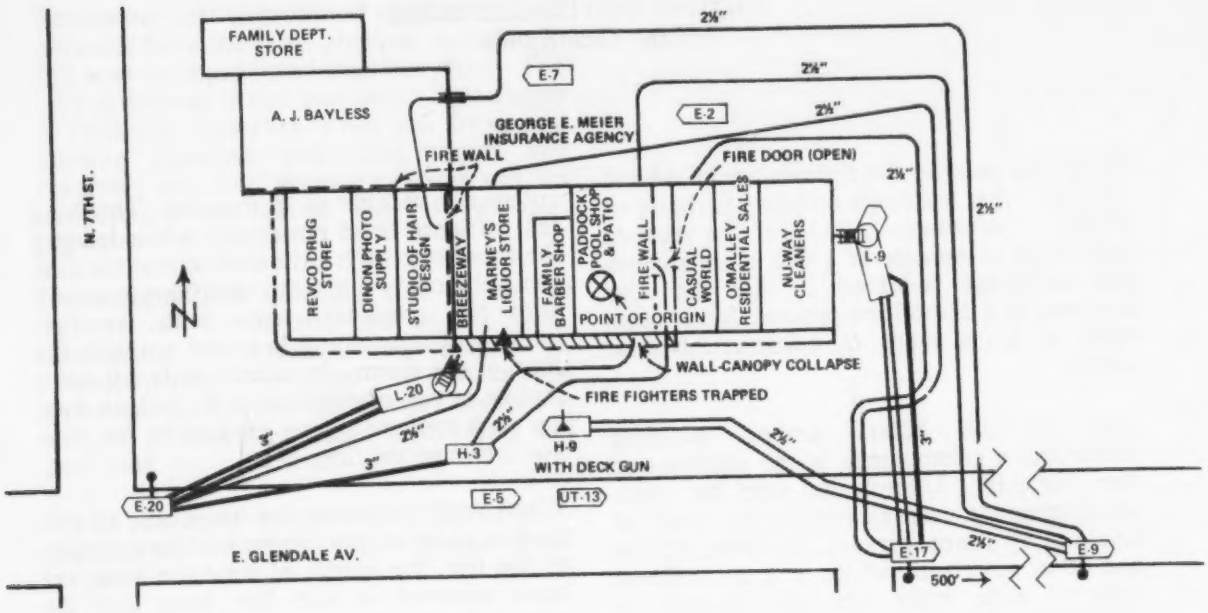
Fire Fighter breaks leg

But nearby, Fire Fighter Paul Lynch was on a ladder, using a hose to hit the cockloft fire, and Fire Fighter Ronald Hayes was helping him. The canopy collapse spun the ladder around and Lynch broke a leg. After the first shower of bricks from the wall, Captain Billy

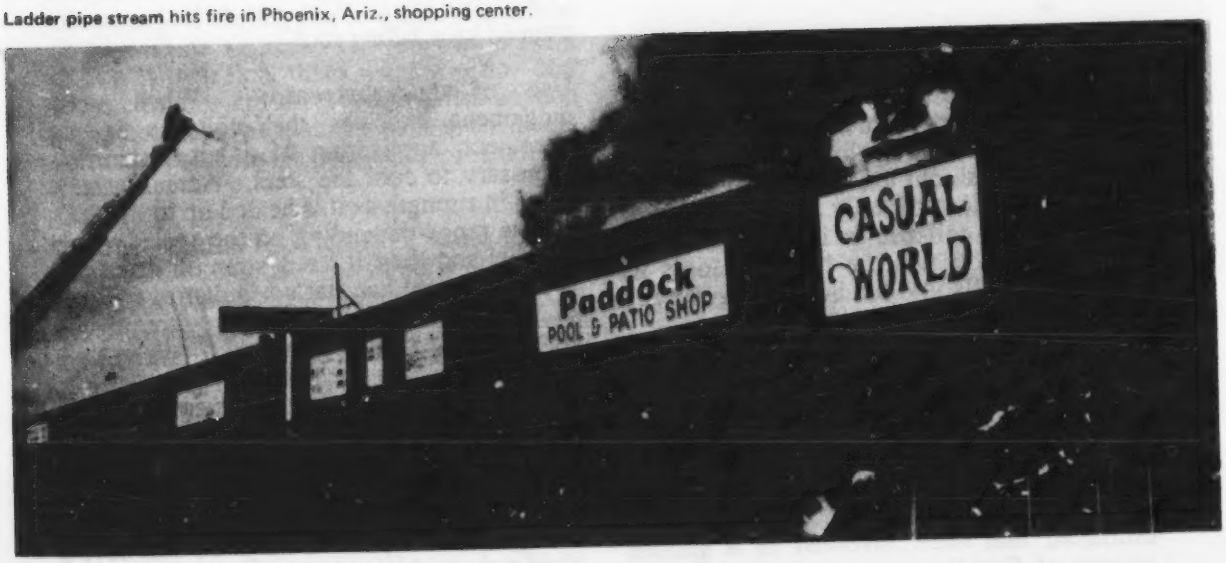
Shields rushed to the ladder to help the men and as he reached them, he was hit by more bricks. Shields received a head injury, and he and Lynch were admitted to a hospital. Hayes was released after treatment at the hospital.

Immediately after the collapse, a request was made for all available ambulances and a third alarm was struck at 9:51 a.m. to bring Engines 8 and 18 to the fireground. Seven minutes later, after all fire fighters had been accounted for, the third-alarm engine companies were returned to service.

According to Bob Blivin, the fire department's chief investigator, the fire was probably caused by an electrical malfunction in the cockloft over Paddock Pool-possibly igniting combustible ceiling material in that store. The roof and cockloft were completely destroyed in the Paddock Pool store area.



Ladder pipe stream hits fire in Phoenix, Ariz., shopping center.



Dangers of Steel Bar Joists And Noncombustible Buildings

Excerpted from Fire Engineering
by: Dick Sylvia

One of the reasons fire fighters are killed and injured is that buildings collapse-partially or totally. Unfortunately, one of the reasons this is true is because of a lack of awareness that buildings involved in fire are also involved in a demolition process that is more rapid in some types of construction than others.

One of the killers among building construction components is the unprotected steel bar joist. Unprotected steel bar joists are commonly used to support the roofs of single-story stores, garages, factories, offices and other structures where it is desirable to have a wide span free of columns at minimum cost.

The flat roof supported by bar joists can have a board, plywood, steel or insulation-type composition board deck with a built-up covering of tarpaper layers, each swabbed with hot tar, with a small stone finish. With the exception of the steel deck and the stone finish, all this material is combustible and under heavy fire conditions can add fuel to the fire.

However, the most usual cause of collapse of bar joists is the amount of heat generated by fire within the building. Either the bar joists are heated to the point of distortion or the bar joists expand under high heat to the point where they push out a wall enough to cause collapse. The fact that only a small portion of the wall may collapse is immaterial. The important fact is that the bar joist loses its support and falls into the building, generally bringing more bar joists with it.

Danger signals: Once a working fire has taken over a building with unprotected steel bar joists, the integrity of the roof is in serious danger. The intensity of the fire serves as a warning to fire fighters entering a building with bar joists. It has been estimated that once involved in a sizable amount of fire, the roof can be expected to collapse in as little as 15 minutes. The thing that officers must remember when leading their men into such a situation is that the time limit-obviously subject to variations in accord with fire conditions-starts with the first buildup of threatening heat and not with the time of the alarm. In other words, all but a minute or two of your safe time under a steel bar joist roof may have expired by the time you arrive on the fireground.

When smoke conceals the bar joists, all you have to go by is your estimate of the intensity of the fire, the length of time the steel has been exposed to the fire heat and the knowledge that steel can be expected to fail at 1100° F. There is no way I know of determining that temperature when you are fighting a fire.

When you can see the bar joists, expect them to collapse when they are red or cherry red-and for practical purposes it doesn't make any difference which color they are even if you can differentiate between the shades. If the steel is white hot, your safe time elapsed some time ago. Get out before you are trapped by a falling roof.

Use of hose stream: When good judgement indicates that collapse is not imminent, application of a hose stream is necessary to cool the steel. Actually, steel gains in strength as it is heated up to the 800-degree range-depending on the specific type of steel-and then it loses strength as it gets hotter. If steel has started to distort because of heat, cooling it with a hose stream will freeze it in its distorted shape.

So when you enter a building with unprotected steel bar joists, you have two warning signals and an axiom to remember that may save your life. A heavy fire involvement for a brief time means probable collapse. When you see bar joists that have a vivid red-or white color, expect collapse. As for the axiom, anticipate the collapse of any

roof supported by unprotected steel, whether it be in the form of bar joists or unprotected steel beams and columns.

Remember that unprotected steel beams and columns have the same physical reactions to fire heat as unprotected steel bar joists. The only difference is that they take a little longer to collapse. However, when you arrive at a burning structure with steel beams and columns, you don't know their sizes and the temperature to which they have been exposed.

Noncombustible building: As far as fire fighters are concerned, one of the most misleading construction terms is "noncombustible building." That means the building won't burn, and it won't because it is made of steel-steel frame, steel siding and steel roof.

What you must remember is that a non-combustible building will collapse when involved in a contents fire.

When materials that will burn are placed inside a noncombustible building, they provide the fuel for a fire that can generate enough heat to cause the collapse of the building. Don't be fooled by the external steel you see when you approach a fire in such a building. Be warned by the steel and know that you can expect it to collapse if the fire inside gains enough intensity for a sufficient time.

Obviously, if the fire can be quickly darkened down with an aggressive attack with a 1-1/2 or 2-1/2- inch line, that's what you do. But if the contents are involved in a fire beyond the extinguishing capability of such an attack, you must consider the possibility of structural failure.

A large volume application of water from a safe position is vital. The use of a deluge set or a deck pipe stream through a doorway is the only way you can hope to knock down the fire and at the same time protect the lives of the fire fighters.

When a building is built to collapse when involved in fire, it makes no sense to risk the lives of fire fighters.

Noncombustible Buildings-Death Traps for Fire Fighters

Excerpted from Fire Engineering

by: Dick Sylvia

When used to designate a type of building construction, the term "noncombustible" becomes an illusion of safety that conceals the inherent danger to fire fighters that is associated with this type of construction.

Two things must be kept in mind when responding to a fire in a noncombustible building:

1. The building itself will not burn, but it is likely to collapse during an interior fire.
2. Although the structural components of the building will not burn, the contents will usually burn.

When a working fire occurs in a noncombustible building, you must expect sections-or all-of the building to collapse. When faced with this danger, fire fighters must get out of the building before collapse becomes imminent.

Construction: Common to noncombustible buildings is an unprotected steel frame. The roof may be supported by arched steel trusses or flat steel trusses, more commonly known as bar-joists. In some noncombustible buildings, the roof rests on steel I-beam rafters and steel purlins (the I-beams connecting the rafters to provide attachment for the roof deck).

The walls can be made of flat steel sheets-often corrugated steel in older buildings-corrugated asbestos cement board or concrete blocks. Except when the wall is made of cement blocks, the columns are always steel. Concrete block walls may or may not have steel columns.

Obviously, the all-steel walls or those with asbestos cement board on steel framing will collapse independently of roof collapse when fire heats the steel sufficiently. Roof failure alone also may cause walls to collapse. When the building has unprotected steel trusses-either arched or bar-joists- expansion or twisting of the trusses can cause collapse of concrete block walls. It is important to remember that a great difference in temperature between the fire-heated interior side of a concrete block wall and the outside of the wall can cause the wall to crack, bulge and fail.

Initial attack: With these facts in mind, the first-in company officer at a serious fire in a noncombustible building must make some critical decisions during his initial size-up. He has to estimate the effect of the fire on the stability of the building in terms of heat being produced by the fire and the length of time it has been burning at high intensity. In some cases, he may estimate that the building will maintain its integrity for as long as 10 or 15 minutes. In other cases, the indications may be that the building is within five minutes or less of partial or total collapse.

A safe rule is that a fully involved noncombustible building is about to collapse. Keep in mind that you did not build this death trap and your first responsibility in such a situation is to protect the lives of your fire fighters. They cannot be replaced, but the building can.

The first-in officer also must realize that a working fire in a noncombustible building must be extinguished as rapidly as possible. We are not discussing the fire that can be quickly darkened down with a 1-1/2-inch line. We are considering a fire of sufficient volume to provide a challenge.

The officer must react to that challenge by putting into operation a stream that is large enough to reduce the volume of fire. While a 2-1/2-inch line-or a 1-3/4 -inch line with an automatic nozzle--may be adequate for some fires, the use of master stream equipment may be the first best move to take at other larger fires. Water damage is of no consideration when the immediate possibility is collapse of the building.

Looking ahead: Noncombustible buildings are becoming more popular for

industrial, warehouse and even office occupancies. Before more are built in your community, you should endeavor to get the odds more on your side by fighting for changes in building codes.

If noncombustible buildings were fully sprinklered--including office areas that sometimes are built inside industrial and warehouse occupancies--your chances of being able to extinguish a fire without collapse of the building would be greatly increased. Require a fire detection system that transmits an alarm to your dispatch center and you will further improve the odds.

As in any other building seriously involved in fire, roof ventilation is a prime need in a noncombustible building. The problem is that the time between flashover and structural collapse is so short in noncombustible buildings that the roof can already be unsafe by the time the first companies arrive.

Although the roof cannot be vented by putting men on the roof, it can be vented if your building code requires plastic skylights or automatic vents on the roof. Fire heat will quickly melt out the plastic in the skylights or cause the automatic vents to open.

Curtain boards, or draft curtains, act to confine the early hot gases within a limited area under the roof. By preventing mushrooming of the hot gases, heat buildup is concentrated within the curtain board area with the result that automatic devices depending on heat for activation-sprinklers, roof vents, plastic skylights-operate earlier in the fire. Earlier operation of these devices slows fire spread and aids extinguishment.

To get these built-in fire protection aids in the next noncombustible building that will be erected in your community, you have to speak now and tell the code officials, building owner and prospective occupant the facts about noncombustible buildings.

Lightweight Construction

Tests Open Fire Service Eyes to Special Hazards

Excerpted from Western Fire Journal - Jan 1982

By Capt. John Mittendorf

Los Angeles City, CA Fire Dept.

Executive Summary

During the last few months, we have highlighted several articles on building construction-with the last edition pointing out the particular problems encountered when fighting fire in certain contemporary construction. Recently, the L.A. City Fire Dept. conducted fire failure tests of several types of contemporary lightweight construction. This is what they discovered...

In Los Angeles, California as well as other cities across the country, fire departments are discovering that fires in lightweight building construction are yielding different results than comparable fires in conventional construction. Comparing the size of what there is to burn (2 x 4's and half inch plywood in tension and compression vs. conventional wood joist construction) it is no surprise that today's firefighter is with newer construction experiencing partial or total structural failure in a short period of time.

Recently, several structure fires in the Southern California area graphically illustrated this fact. During December of 1979, the Orange County Fire Department responded to a common structure fire-single family dwelling with fire showing from the garage. Approximately ten minutes after arrival, the entire roof collapsed injuring nine firefighters. Roof construction-*Metal Gusset Plate Trusses* (See WFJ, May/1980). During August of 1981, the City of Los Angeles Fire Department responded to a common structure fire. First in companies observed a one story multi-occupancy commercial with some fire from the roof over the involved occupancy. Approximately two to three minutes after arrival of the initial companies, the entire roof over the involved occupancy collapsed. The roof was of *Open Web Construction.*

Analyzing these fires, and other fires across the country that have occurred in similar lightweight construction, reveals several primary considerations that should be given thought to when working with lightweight construction:

1)Time - required for failure
2)Speed/Rate - of failure
3)Familiarity-with building/construction.

These factors were highlighted during some tests that were performed during May of 1981. Due to a lack of available information, and to better understand some of the problems that are presented in this relatively new area of firefighting, several major manufacturers of lightweight building and roof systems were approached. They were asked to subject representative samples of their products to fire conditions so that the results could be anlyzed. Products were donated with the following roofs to be represented: *1) Metal Gusset Plate Truss 2) Wooden I Beam 3) Open Web Construction 4) Panelized.*

The general concept of the test would be to utilize typical construction, observe and record behavioral characteristics under fire conditions. The following parameters were used:

1)Construction equal to what would be found in common applications.
   a)Trusses to use correct "on center spacing."
   b)Utilize 1/2", 5/8" or 3/4" "CDX" plywood as the decking.
   c)Trusses to be hung or supported as found in normal installation.
2)Span of roof limited to size of donated products.
3)Roofs to be suspended over the fire.
4)Fire to be approximately equal for each test.
5)Each test fire generated from four gallons thinner and sawn up pallets.
6)No live load to be imposed on roofs.
7)Test to be timed fron start of ignition.
8)A time limit of six minutes per test was used.

It was assumed that the majority of this lightweight construction would fail in less than six minutes. If the particular test construction had not failed in six minutes, the fire would be extinguished and the construction examined for results.

If the test construction failed in less than six minutes, the fire would be extinguished and the construction examined for results.

Following are the fire tests that were conducted and what was learned from each sample:

1)WOODEN I BEAMS
(See WIB Photo 1)

Span: 12 feet **Decking**: 1/2" CDX plywood **O.C. Spacing**: 32 inches of I Beams **Application**: Roof System **Time of Failure** : 3 minutes, 20 seconds.

SUMMARY

WIB 2 shows the test sample after ignition. WIB 3 shows fire beginning to show through the half inch decking at the rear, and WIB 4 shows the rear decking well involved. In WIB 5, the interior I Beam is beginning to buckle with the decking beginning to sag in WIB 6. In WIB 7, the rear portion is beginning to collapse. The fire was then extinguished. WIB 9 emphasizes the result of fire on the plywood stem of the I Beam. WIB 10 shows the underside of the roof and the remains of the plywood I Beams.

CONCLUSIONS

As evidenced by this test, once the 3/8" plywood stems burn and weaken, the entire structure weakens and fails. It is interesting to note that with fire impinging on the half inch decking, it took two minutes for fire to show through the plywood decking.

This type of contruction is used as floor joists in floor systems and rafters in roof systems.

2)OPEN WEB CONSTRUCTION
(See OWC Photo 1)

Span: 20 feet **Decking**: 1/2" CDX plywood **O.C. Spacing**: 24 inches of trusses **Application**: Roof system **Time of Failure**: 5 minutes.

SUMMARY

OWC 2 shows the test sample 25 seconds after ignition. OWC 4 shows fire beginning to show through the 1/2" plywood decking. In OWC 5, the decking is well involved in fire with burning plywood dropping from the decking in OWC 6. OWC 7 shows the roof after failure.

CONCLUSION

In this test, failure of the sample roof was rapid and complete. It was obvious that the weak point of this construction is the junction of the 2 x 4 chord, steel tube webbing and pins. OWC 8 Consider that a 6" longitudinal slot and 5/8" (depending upon application) hole are cut into the 2 x 4 chord at each junction point. It is easy to see that a major percentage of the 2 x 4 has been removed. OWC 9 shows an end view of the 2 x 4 bottom chord after five minutes of burn. Notice that the char is almost complete.

After collapse of the test sample, it was evident that each junction point (chord, pin and tubes) that had significant char had failed. This was accomplished by the tubes and pin pulling out of the chord, and was most evident on the bottom chord. See OWC 10 and 11. OWC 12 shows a charred top chord. There is no structural strength remaining.

3A)METAL GUSSET PLATE TRUSSES
(See MGP-A Photo I)

Span: 30 feet **Decking**: 3/4" CDX plywood **O.C. Spacing**: 16 inches of trusses **Application**: Floor system **Penetration depth of gusset plates**: 3/8" **Time of failure**: 1 minute, 20 seconds.

SUMMARY

MGP-A 2a and 2b show the test sample and underside view before ignition. Notice in MGP-A 2b the large metal gusset plate on the bottom chord is the junction of the ends of the two 2 x 4's used for the bottom chord. MGP-A 3 and 4 show the test fire. MGP-A 5 shows the failure of the construction..

CONCLUSION

The early collapse of this test sample was caused by two factors inherent to this type of construction. **1**)It was found that once the 2 x 4 was charred to a depth of 1/4", the gusset plates would pull out of the 2 x 4's (See MGP-A 6,7,8 and 9). **2**)Because the 2 x 4 ends are butted together and held by gusset plates (MGP-A 10), there is no structural integrity once the gusset plate has pulled free-leaving the 2 x 4's to separate and cause failure. Compare the mitered/glue joint of open web construction (MGP-A 11) to the metal gusset plate joint (MGP-A 12).

It is common to find these butted joints in metal gusset plate trusses when the lengths of 2 x 4's used in this construction exceed 22-24 feet. It is not cost effective to purchase 2 x 4's in lengths exceeding 22-24 feet. Also, the longer the 2 x 4, the greater the susceptibility to warping and twisting.

3B) METAL GUSSET PLATE TRUSSES
(See MGP-B Photo1)

Span: 1/2" and 5/8" CDX plywood **O.C. Spacing**: 32 inches of trusses **Application**: Roof system (Gable) **Penetration depth of gusset plates**: 3/8" **Time of failure**: Did not fail in the 6 minute time period.

SUMMARY

MGP-B 2 shows an interior view of the roof and center webbing supports. MGP-B 3 and 4 are the fires progress on the interior of the roof with fire beginning to show through the plywood decking in MGP-B 5. In MGP-B 6, the burning decking is more evident. MGP-B 7 shows the roof after the fire had been extinguished (6 minutes). The sheet of plywood at the ridge of the roof is 5/8" CDX, while the bottom sheet is 1/2" CDX. In MGP-B 8, the plywood has been reversed, 1/2" CDX at the top, and 5/8" CDX at the bottom.

CONCLUSION

This style of MGP truss construction resisted failure much better than the preceding tests utilizing MGP truss construction employed as floor joists. The MGP truss utilized as floor joists were constructed with the bottom chord comprised of two 15 foot 2 x 4's butted together at the center of the clearspan and secured by a gusset plate.

The MGP Truss used in this test was constructed with a continuous 2 x 4 used as a bottom chord (see MGP-B 4). This was instrumental in the trusses ability to resist failure.

However, when the test fire was extinguished at the six minute mark, the vertical webbing had failed and the top chords were beginning to separate (MGP-B 8). Upon closer inspection, it was evident this construction was about to fail. Notice in MGP-B 9 and 10 that the gusset plates have pulled loose, destroying the structural bond and strength.

When metal gusset plates (MGP-B 11) are exposed to fire, the following factors will contribute to failure. **1**)Amount of load or stress imposed on a joint. **2**) Ability of the plate to conduct heat to the prongs which will cause the wood to expand and lose its grip on the gusset plate prongs. **3**)Depth of penetration of prongs. Considering 3/8" prongs, once the wood has charred 1/4", there is only 1/8" prong left to create a friction bond.

Another factor that did not prove significant, was comparing 1/2" CDX to 5/8" CDX plywood. The 5/8" plywood did not provide any significant advantage over the 1/2" plywood in comparing their ability to resist fire. Compare MGP-B 7 and 8.

4) PANELIZED
(See P Photo 1)

Span: 8 feet by 8 feet **Decking**: 1/2" CDX plywood and 1 x 6 sheathing **O.C. Spacing**: 24 inches of 2 x 4 joists **Application:** Roof system **Length of test**: 6 minutes.

SUMMARY

The purpose of this test *was not* to specifically test for failure of the roof construction. Fires of any magnitude that occur in buildings with panelized roofs usually burn through the 1/2" plywood and 2 x 4 joists in a short period of time.

The factors that were considered in this test were twofold: 1)Effect of fire on the foil insulation that is stapled to the underside of

these roofs (See P 2) . 2)Comparison of fire on 1/2" plywood and 1 x 6 sheathing. This part of the test was to compare the difference between the roof decking that is utilized today, and the roof decking that was utilized over 20 years ago. P 3 shows the roof with 1/2" CDX plywood on the left and 1 x 6 sheathing to the right. In this test, the test fire would burn for six minutes, be extinguished and the results analyzed with emphasis on the insulation. P 4 shows the fire at 10 seconds with insulation beginning to burn and pull away from the roof. P 5 gives a better view of the burning insulation, while P 6 shows consummation of the insulation and greater fire intensity. P 7 shows fire beginning to come through the 1/2" CDX plywood. P 8 shows good burn-through. In P 9 and 10, you can compare the 1/2" CDX plywood on the right side of the photo to the 1 x 6 sheathing on the left.

CONCLUSION

Exposed to heat or fire, the insulation will flash and begin to pull loose from the underside of the roof. In this test, it took 10 seconds. Two recent fires in the Los Angeles area, involving buildings with panelized roofs have produced similar results. P 11 shows the results of one of these fires. In this photo, the insulation pulled free in an area of the building that only experienced a build-up of heat. The insulation paper consists of tar impregnated kraft paper covered on either side by thin foil. When this paper is exposed to fire or heat from a fire, the foil will peel away from the middle layer of tar impregnated paper (see P12). This paper will then begin to give off flammable vapors which build up between the insulation paper and plywood decking. When ignition temperature is reached, the gas will flash resulting in heavy char to the wood and burning insulation dropping to the floor below. Fire is then able to expose the 2 x 4 joists and plywood decking which will fail in a short period of time. With a build up of heat and burning insulation dropping, it would be possible for a fire to travel the length of a building in a short period of time.

The second phase of this test was to compare the effect of fire on plywood and 1 x 6 sheathing. Observing the end result (see P 9 and 10), it is obvious there is no comparison between the roof decking of today and yesterday. After extinguishment of the test fire, it was still possible to walk on the 1 x 6 sheathing, whereas the plywood was gone. For the firefighter, this means a reduction of time to work on a building utilizing lightweight construction.

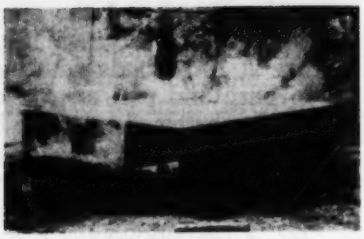
Although most of the test samples were smaller than what would be found in practical applications, and each test resulted in early failure of the construction, consider what today's firefighter will encounter when faced with normal spans, air conditioning or heating equipment - and several truckmen on the roof. Each test was relatively basic, however each test produced similar or identical results when compared with recent fires that have involved this type of construction.

The need for each firefighter to become familiar with new developments that will effect job performance and job safety, and to PREPLAN your operations, cannot be emphasized enough.

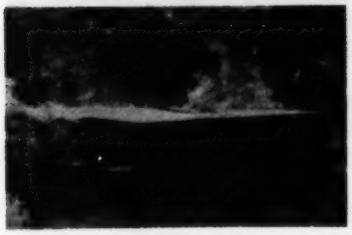
Our next article will consider ventilation methods that have been effective and safe when utilized on lightweight roofs.

WIB 1

WIB 2

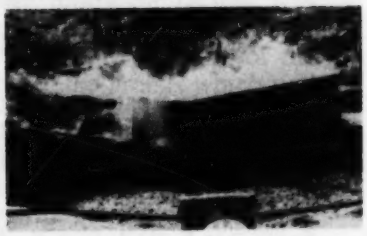


WIB 3



WIB 4

WIB 5



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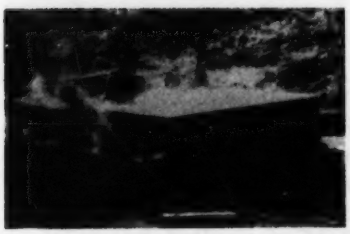
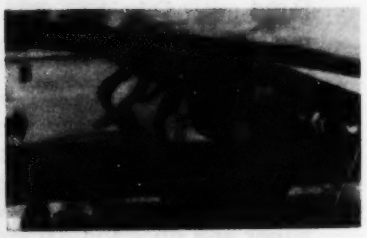
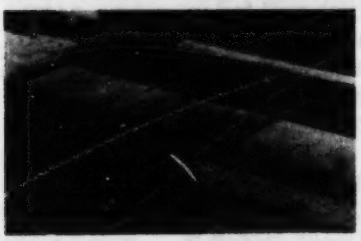


WIB 7

WIB 8

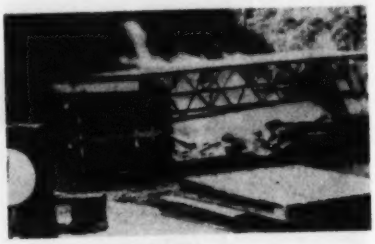


WIB 9



WIB 10

OWC 1



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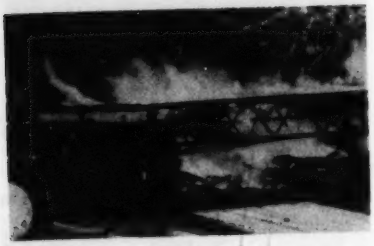

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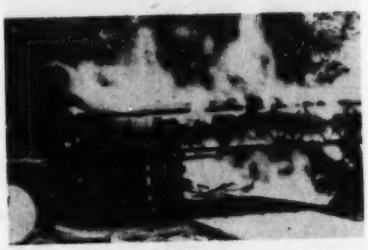
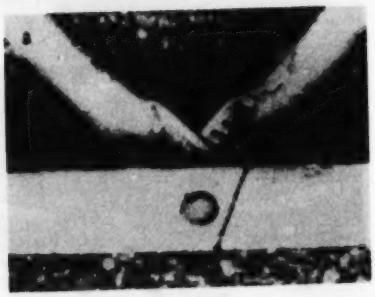


OWC 4

OWC 5

OWC 6

OWC 7

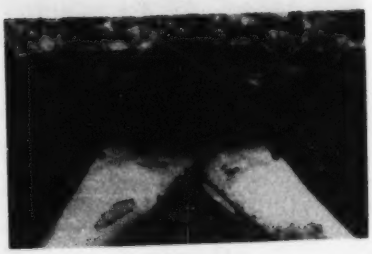


OWC 8

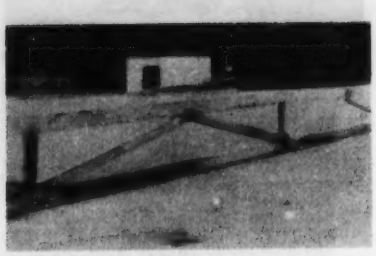
OWC 9

OWC 10

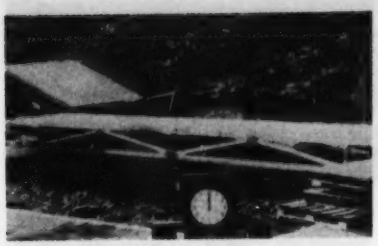
OWC 11



OWC 12



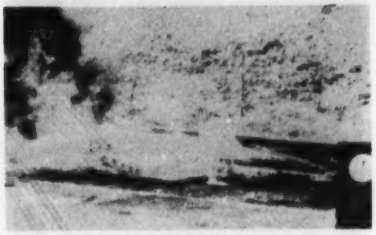
MGP-A 1



MGP-A 2a

MGP-A 2b

MGP-A 3



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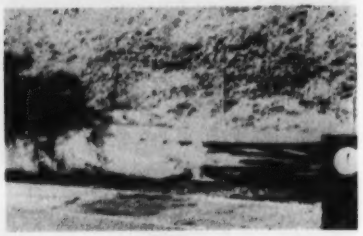
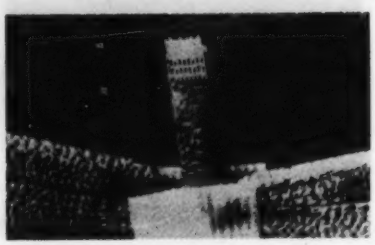


MGP-A 5



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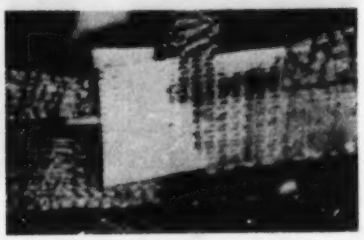

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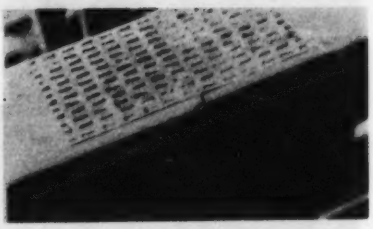

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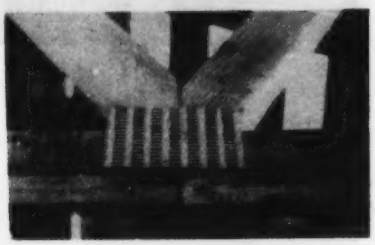

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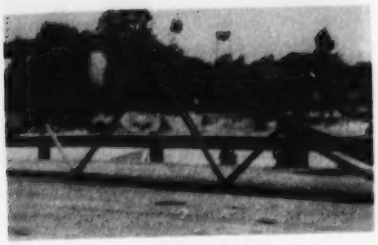

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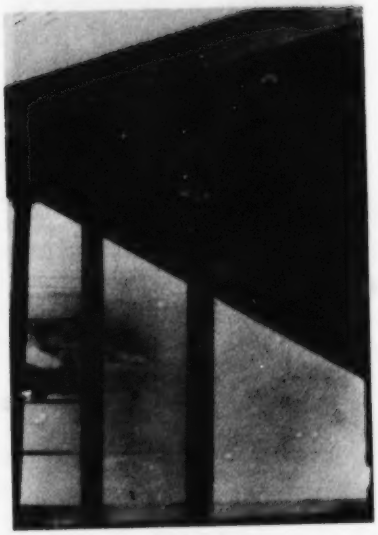

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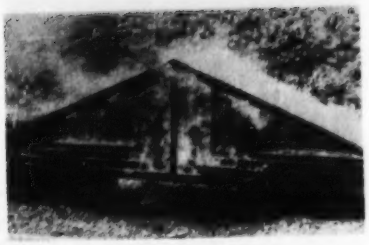

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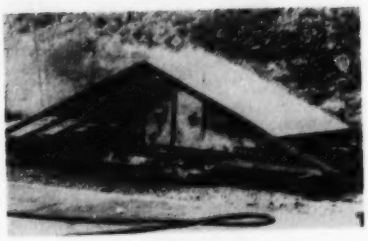

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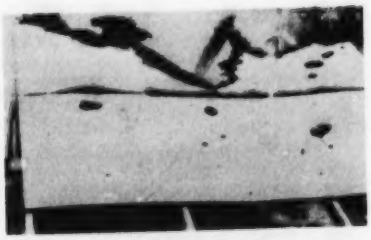

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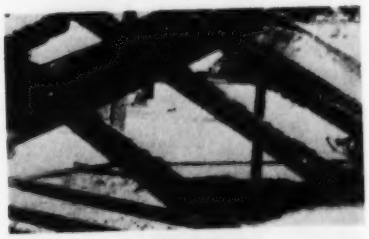

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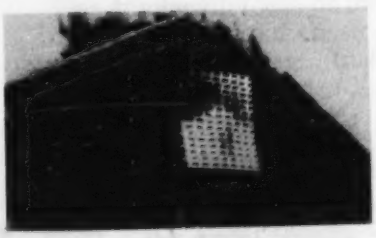

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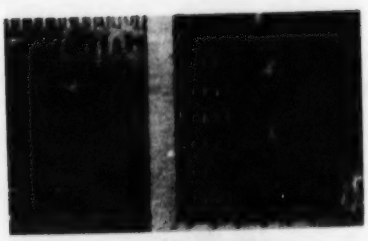
MGP-B 10



MGP-B 11

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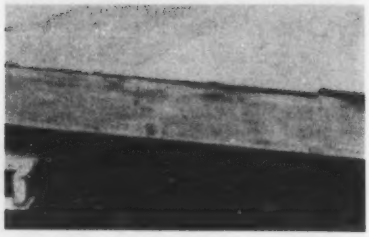
P 2



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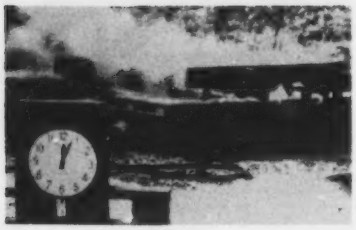

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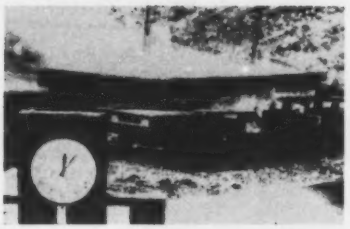

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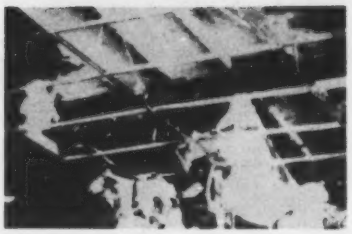


P 11

P 12

Light Weight Roofs May Prove Hazardous to Your Health

Excerpted from Western Fire Journal - Nov 1981

By CAPT. JOHN MITTENDORF
Los Angeles Fire Dept.

Executive Summary
With the modern construction techniques used in today's lightweight roofs, builders are finding a significant savings in materials cost and construction time. This, however, is not a boon to the firefighter-who in many cases must face rapid structural collapse.

Lightweight building and roof construction is currently very popular with architects and building contractors across the country, and for good reason. Considering the present cost of labor, equipment and building materials, it is not economically feasible to build a structure the same as forty years ago. Ease of installation and utilization of lightweight building materials have become the standard during the last twenty years. Heavy timber, laminated beams and 1 x 6 sheathing have been replaced by 2 x 4's and half inch plywood - regardless of building size. As modern architects reduce the size of what there is to burn, todays fire department is losing one of its most valuable fireground factors: TIME.

This article will focus on the four major types of light weight roof construction: panelized, metal gusset plate trusses, open web construction and wooden "I Beams."

PANELIZED
(See PR Photo A)

Description: This roof may be found on structures built of wood, masonry or concrete tilt up slabs. Consists of four major components (PR Photo B): (1) laminated beams, (2) purlins, (3) 2 x 4 joists and (4) 1/2-inch or 5/8-inch plywood decking.

After the walls are erected, and depending on the construction technique, the roof is usually constructed in the following manner. Laminated beams of various sizes (6" x 36" common) are initially installed spanning the length *or* width of the building. These beams are usually supported at their ends by pilasters, wood or steel posts or saddles. Wood or steel posts may provide additional support along the clearspan. These beams are normally spaced between fourteen and forty feet apart. Beams will be bolted together to provide lengths well in excess of one hundred feet (PR Photo C).

Supported by these beams, wooden purlins are installed with metal hangers on eight foot centers. Common size for purlins is 4" x 12" with the length depending on the spacing of the beams. Joists measuring 2" x 4" x 8' are installed with metal hangers on two foot centers between the purlins and run parallel to the beams. Sheets of plywood, 4' x 8' x 1/2", are nailed over this framework. Plywood is then covered with asphalt or tar paper roofing material. A three-layer insulation paper is stapled to the underside of the roof between the beams and purlins (PR Photo D). This paper offers little protection to the 2 x 4 joists and 4 x 8 sheets of plywood. This paper consists of tar impregnated kraft paper covered on either side by thin aluminum foil.

Hazards: Supports for beams of four inch hollow steel pipe may be found. Expect weakening and or collapse of these supports with failure of large portions of the roof under heavy fire conditions. When the insulation paper is subjected to fire, the foil will peel away from the middle layer of tar impregnated paper (PR Photo E). This paper will then begin to give off a flammable gas which builds up between the insulation paper and plywood decking. When ignition temperature is reached, the gas will flash - resulting in heavy char to the wood and

burning insulation dropping to the floor below. Fire is then able to expose the 2 x 4 joists and half inch plywood panels which offer little resistance to fire.

OPEN WEB CONSTRUCTION
(See OWC Photo A)

Description: Open web construction consists of bottom and top parallel wooden supporting beams, called chords, which are cross-connected by steel tube web members. The top chord (supported) under load would offer a bridging effect causing the top chord member to be in compression and the bottom chord member (unsupported) to be in tension. Open web construction is prefabricated at the factory before installation with either parallel chords laid on edge or with flat laid chords. The steel tube web members are prefabricated from one inch to two inch cold rolled steel tubing with the ends pressed flat into a semicircular shape, and a hole punched through each end. These flattened ends are then inserted into slots in the chords. Steel pins (up to one inch) are then driven through the chord members and through the flattened ends of the web members, completing the assembly (OWC Photo B). When the prefab joists are installed, the top chord members are secured to the top of bearing walls with the bottom chord remaining unsupported away from the wall (OWC Photo C). Spans to seventy feet are possible using a single 2 x 4 (OWC Photo D) or two 2 x 3's (OWC Photo E) as top and bottom chord members. Two by fours, lengths of seventy feet, are made possible by joining different lengths of 2 x 4's in glued, mitered "finger joints" (OWC Photo F). Normal on center spacing is two feet. Used in floor and roof systems.

Hazards: The hazards of this roof are many. Basically, this roof is constructed of 2 x 4's or 2 x 3's under tension and compression and half inch plywood decking. These components offer minimum resistance to fire. Some structures leave the chords exposed, which will increase the exposure hazard and assist in larger areas of the roof being exposed to fire. Expect to find no fire stops in this construction. Due to the size of lumber and chord members in tension and compression tied together, expect rapid failure of this construction. When 2 x 4's are laid flat as chords with half inch plywood decking, firefighters only have to cut two inches deep to cut through the chords, resulting in partial roof failure.

WOODEN "I BEAM"
(See WIB Photo A)

Description: Consists of three main components (WIB Photo B). (1) top chord, (2) bottom chord and (3) 3/8-inch plywood stem. The stem is joined to the top and bottom chords by a continuous glued edge joint. Two by four's are used as chords, but 2 x 3 chords are very common. Two by three chords may resemble plywood because of laminations. However, the laminations (trade name of MICRO LAM) or veneers run horizontally in the chords (WIB Photo C). Micro Lam differs from plywood where every other veneer is ninety degrees to the preceding veneer (WIB Photo D). The Micro Lam veneers are stronger than solid sawn lumber. In the 2 x 3 configuration, spans up to forty feet will be found. Until adequately braced and the plywood decking is nailed down, this construction is very unstable (WIB Photo E). Common on center spacing for this construction is two feet, covered with half inch plywood. Used in floor and roof systems.

Hazards: What there is to burn consists of a 3/8 inch plywood stem and 2 x 3 or 2 x 4 chords. It will take little time for the 3/8 inch plywood stem to burn, weaken and cause collapse of the chords and roof. Buildings will be found with open and unprotected chords. Common practice is to run ducting of various sizes through the stems, which removes a good percentage of the stem and gives fire horizontal access to enclosed trusses (WIB Photo F). As with other lightweight roofs, depth of the cuts for ventilation purposes is critical.

METAL GUSSET
PLATE TRUSSES
(See MGP Photo A)

Description: Rough carpentry wood trusses used in residential and commercial applications utilize 2 x 4's held together by metal gusset plate connectors (MGP Photo B). This truss system is enjoying widespread use in roof, floor, rough window and rough door openings (MGP Photo C). Trusses for roofs may be constructed in a wide variety of forms. Regardless of form, these trusses share common features. Trusses are constructed of top chords, bottom chords and webbing. The supports

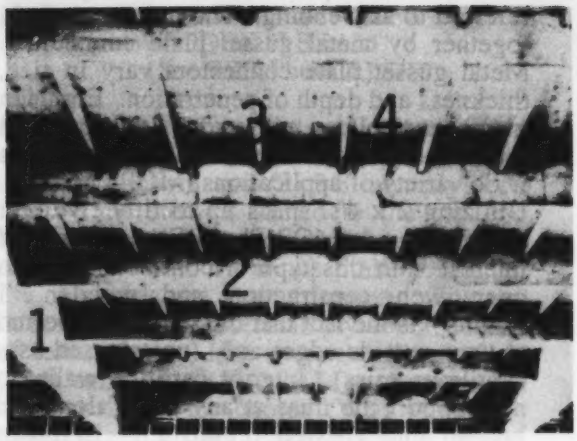
between the top and bottom chords are referred to as webbing. The trusses are held together by metal gusset plate connectors. Metal gusset plate connectors vary in size, thickness and depth of penetration. Eighteen gauge steel plates with prongs that produce 3/8" penetration are common and used in a wide variety of applications (MGP Photo D). Utilizing 2 x 4's, spans up to fifty five feet will be found (MGP Photo E). A point of interest with this type of construction (also open web construction and wooden "I Beams") is the fact that trusses are supported at their outside edges only (unless used as a cantilever truss). Interior partition walls do not support the truss at any point along the bottom chord (MGP Photo F). Eighteen gauge "roof truss clips" may be found at various chords. These clips are nailed to the bottom chord and to the top plate of the interior wall (MGP Photo G). Roof truss clips provide some lateral stability for the partition wall. In this configuration, interior partition walls could be classified as "free standing."

Hazards: Extensive use of 2 x 4 trusses with metal gusset plate connectors equals short burning time and early failure and collapse. These trusses are under tension and compression, and when the bottom chord or webbing fails - either from connector plates that have pulled out or from deep char- the truss will fail. When the metal connector plates and surrounding wood are exposed to fire, the plates will fail in a short period of time by pulling out of the wood. The bottom chord of the truss has replaced the 2 x 6 or larger ceiling joist of conventional construction. Coupled with the fact that these bottom chords do not rest on the interior walls which offer additional support, you can expect total collapse of portions or the entire roof in a short period of time. As in other truss type construction, depth of cuts for ventilation purposes are critical.

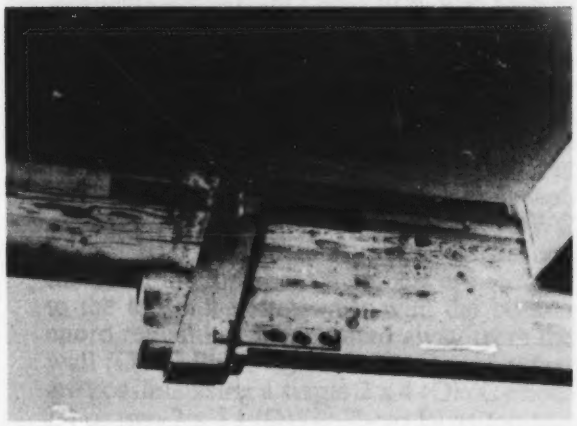
As you look around your district to familiarize yourself with these different types of construction, you may find more than one type of lightweight construction in one building. Photo (A1) shows open web construction, wooden "I Beam" and conventional construction. Photo (B1) shows conventional and open web construction. Know the difference and how you would handle each specific type under fire conditions.

In the next article, we will look at some tests that were performed on these lightweight roofs to determine how they react under fire conditions.

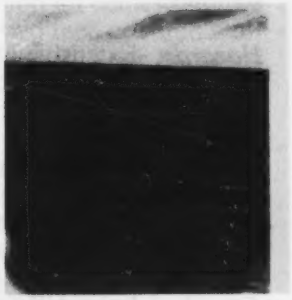
Panelized Roof (PR) Photo A



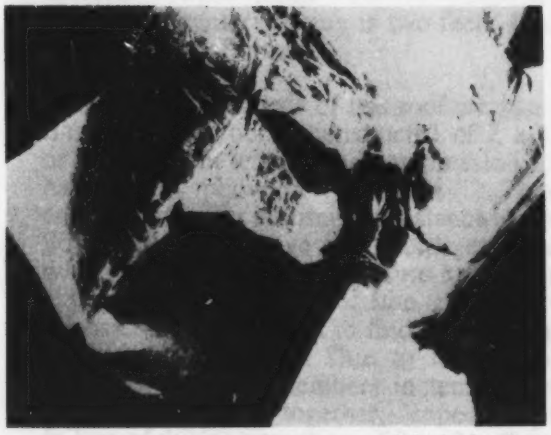
PR Photo B



PR Photo C

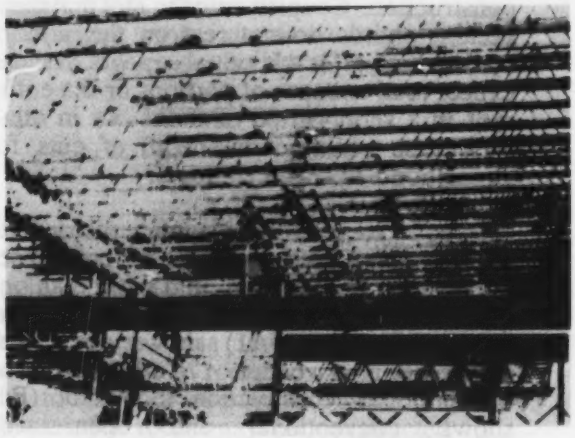


PR Photo D

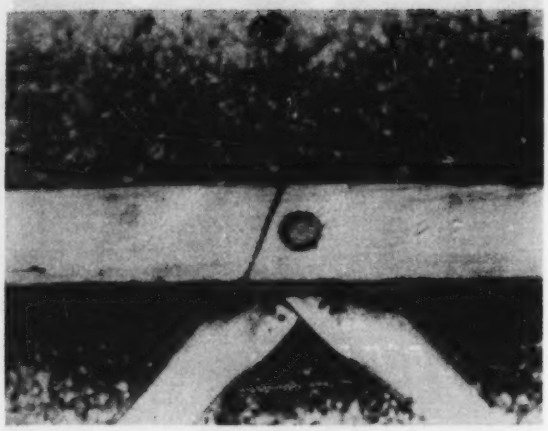


PR Photo E

L.A. City Fire Dept. Photos



Open Web Construction (OWC) Photo A



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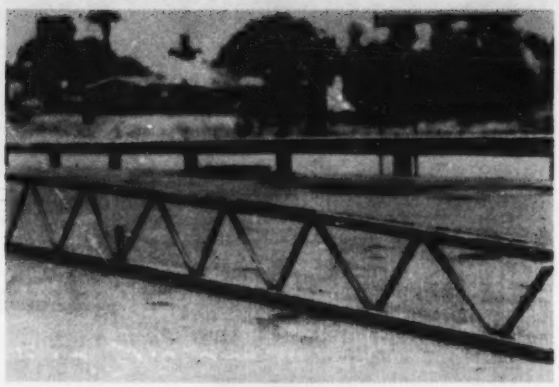

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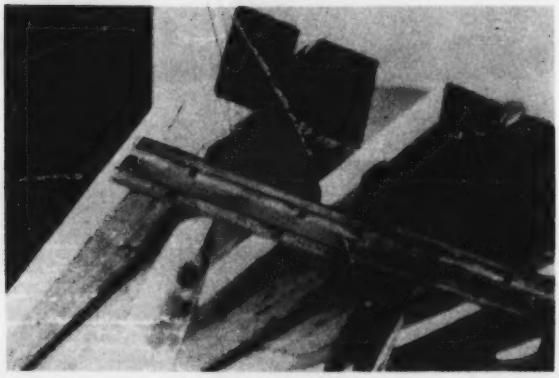
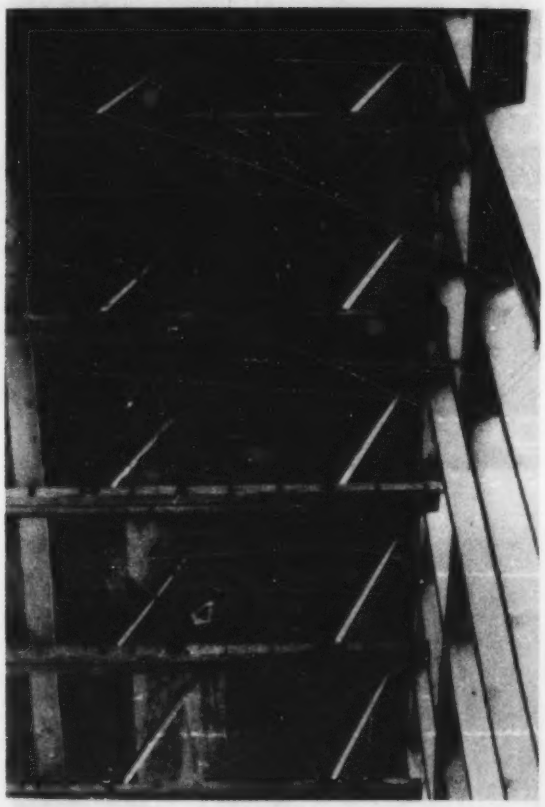
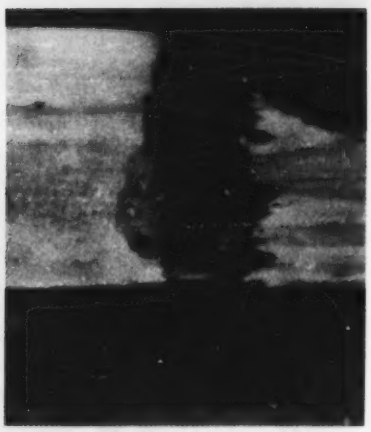


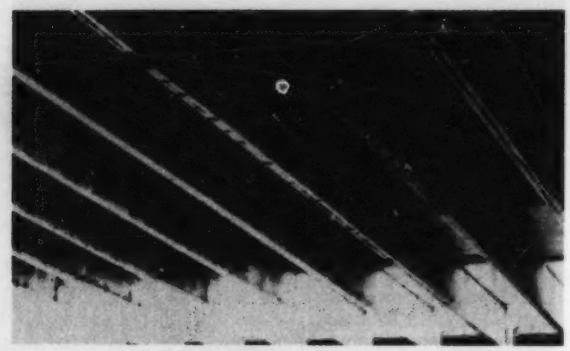
OWC Photo E



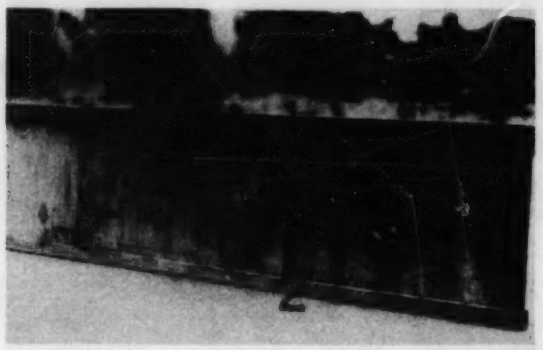
OWC Photo C



OWC Photo F



Wooden "I Beam" (WIB) Photo A



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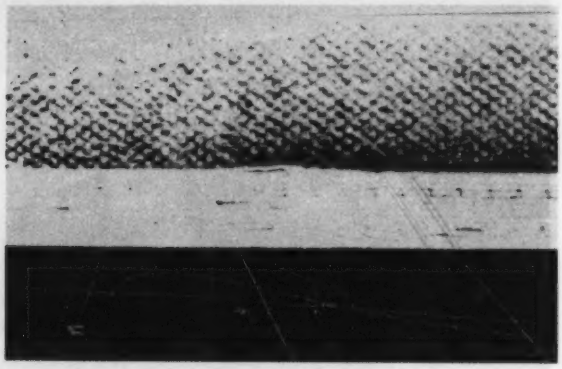

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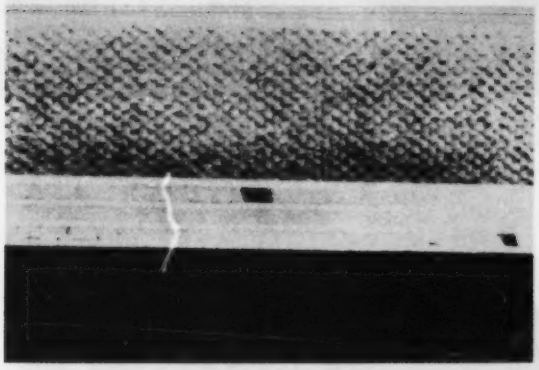
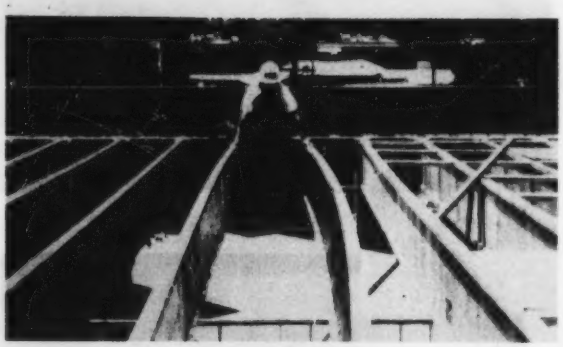
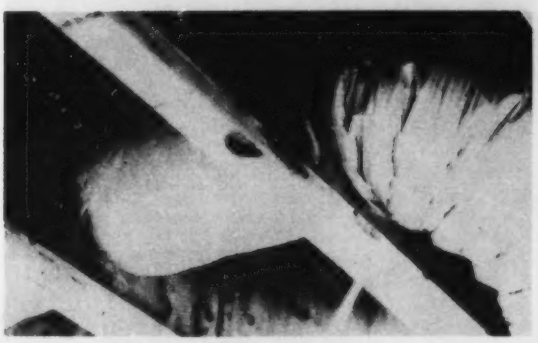


WIB Photo D



WIB Photo E



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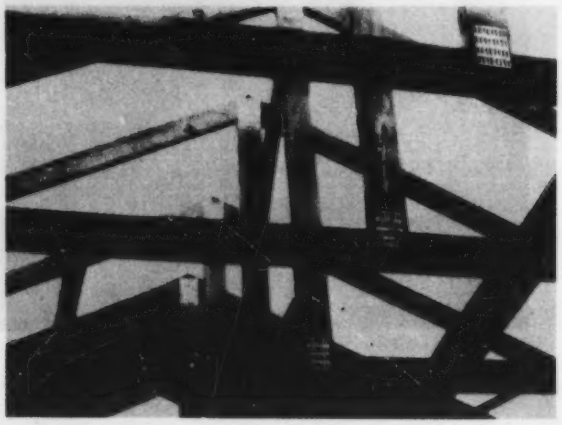
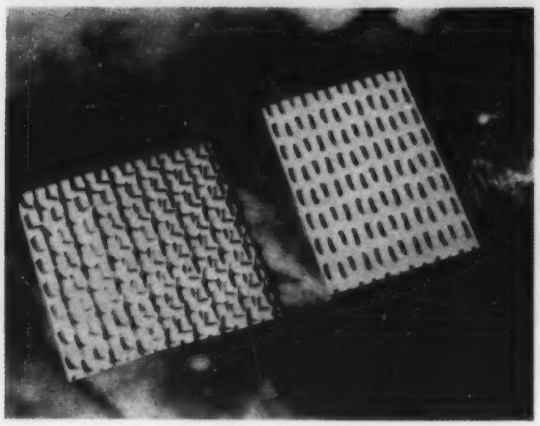
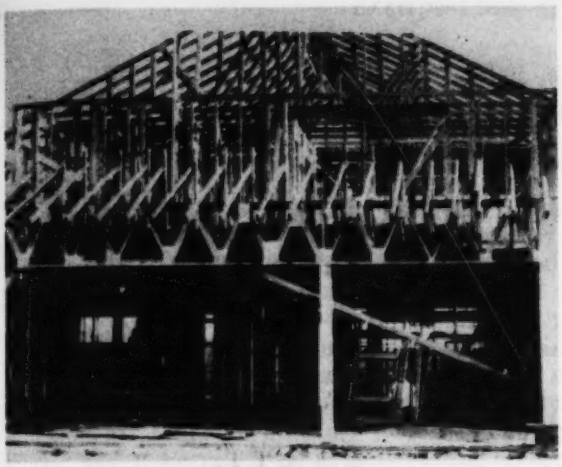


Metal Gusset Plate Trusses (MGP) Photo A



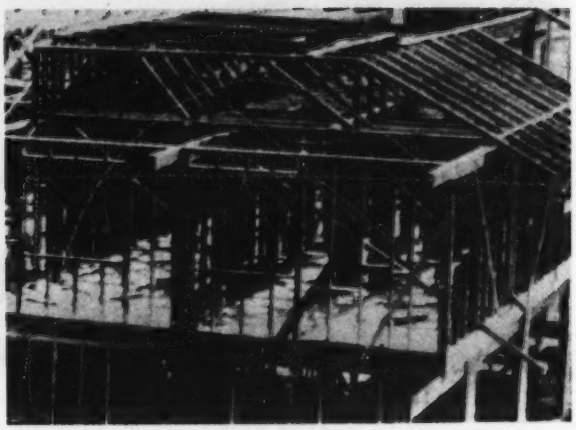
MGP Photo B



MGP Photo C

MGP Photo D

MGP Photo E



MGP Photo F

MGP Photo G

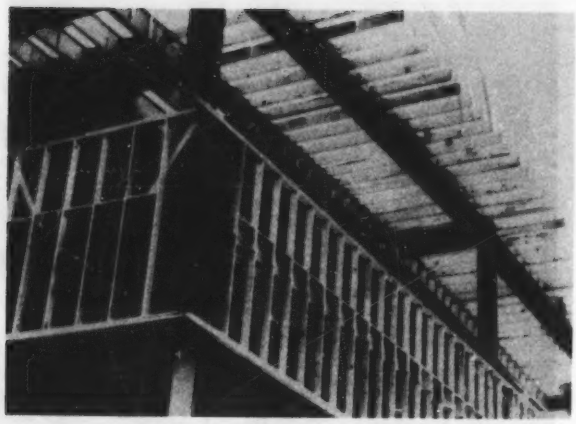


Photo A1

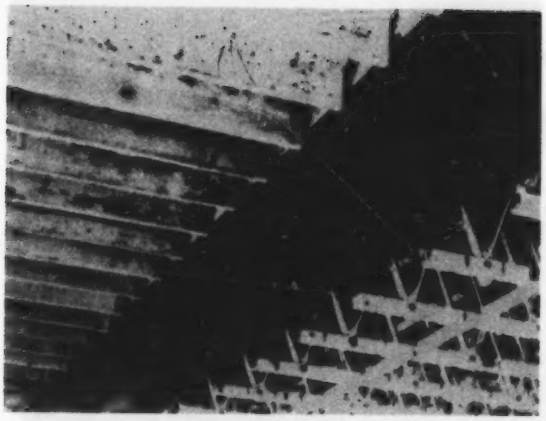


Photo B1

The Built-In Hazards Of Roof Construction

Excerpted from Western Fire Journal - July 1981

By Capt. John Mittendorf

L.A. City Fire Dept.

As architects and the building industry continue to design and build structures that vary in type, design and method of construction, it becomes imperative that firefighters develop a familiarity with the basic construction fundamentals of building and roof types - old and new. Taking a drive through your district or area will reveal a wide range of building methods, roof types and materials used in constructing structures that were built around 1920 - 1930, 1950 and 1970. Each pose a different fire problem and hazard for the modern Fire Service.

Although this article will center on the basic *types* of roof construction and problems encountered, as a firefighter you should be aware of and familiar with the types of construction that may be encountered in *your* district. An easy way to familiarize yourself with basic roof fundamentals and what is current to your district is looking, thinking, and talking about different buildings in your district as you drive through. On fire prevention, as you pull up in front of a particular building, think about the type, construction, strong and weak areas and where and how you would operate on this particular type of construction. As you walk into buildings, ladder roofs, think and talk firefighting, and you will soon find that a quick and fairly accurate size-up of what you will encounter is easily accomplished.

Basically, the Fire Service is fighting fires the same way they did 40 to 50 years ago. Enginemen take hose lines inside and truckmen go to the roof to ventilate. Are buildings the same as they were 50 years or even 20 years ago? Not even close. Therefore, a firefighter who is familiar with the type of building and roof that he is about to work on or in, will do a better job and be a safer firefighter. This article will deal with the basics and is not intended to be technical. It is meant to generate interest, thought and discussion, and to be informative.

CORRUGATED METAL

Description: A fast, inexpensive building (large or small) to erect. Generally a wood or metal structure covered by corrugated metal.

Hazards: Corrugations may be steel, aluminum or in some cases fiberglass. Corrugated steel is the most common - usually 18-20 gauge thickness. Some buildings put plastic or fiberglass panels in the roof as skylights. There is virtually no support between vertical and horizontal structural members. Expect rapid failure of corrugations under fire conditions.

LIGHT WEIGHT CONCRETE -NON STRUCTURAL

Description: A steel or wood structure covered by corrugated metal "Robertson Decking." An airentrained mixture of sand, cement and occasionally peagravel is pumped on top of the decking and wire mesh to a thickness of about 3 or 4 inches; covered by several layers of tar paper.

Hazards: The mixture dries to form a strong, hard surface, and is structurally sound. It is difficult to penetrate with a chain saw or rotary saw with masonry blade. Use a rotary saw with carbide tip wood blade.

SAWTOOTH

Description: Constructed in commercial buildings to yield additional light and ventilation. Constructed with a good grade of lumber with sufficient wood and/or metal supports and bracing internally. The vertical portion is usually "wired" glass with openable panes. The sloping portion is generally covered with 1" x 6" sheathing or plywood.

Hazards: Early failure of metal supports or bracing. Newer sawtooth with plywood decking yields less resistance to fire.

BOWSTRING ARCH

Description: Arched roof with tie rods and turnbuckles offering lateral support. A tie rod with turnbuckles is used below each arch to support the exterior walls. The tie rods pass through the exterior wall to an outside plate. Tension is maintained by turn buckles. The Arch is usually constructed of laminated arches. Two by ten or larger joists span between the arches, covered by sheathing and tar paper.

Hazards: The main hazard is an early failure of the metal tie rods and turnbuckles. The tie rods offer support to keep the arch from pushing exterior walls outward and causing collapse of building.

CONVENTIONAL FLAT ROOF

Description: Wood joists of various sizes are laid across outside walls to outside walls, or across outside walls to interior walls or structural supports. Joists are covered with sheathing or plywood. This is a common roof.

Hazards: The degree of hazard presented by joists is based on the span, size of joist, "on center" spacing, and whether or not they are hung on metal hangers. Roofs covered by plywood instead of sheathing also present a problem. Plywood may be found in from 3/8" thickness on up to 5/8". 3/8" or 1/2" offers little structural integrity under fire conditions.

BRIDGE TRUSS

Description: A flat wooden truss member with sloping ends. Usually a heavy grade of construction. Metal tie rods may be used vertically for additional support. Wooden joists are used between trusses. Usually they are covered with sheathing then tar paper.

Hazards: This depends on the size of lumber used and the span of the trusses. If metal tie rods are used, an early failure of the rods will weaken the strength of the truss.

TRUSS OR RIBBED ARCH

Description: Usually large-sized, wooden members are used to construct the truss. Some arches have multiple beams to form one arch. Wooden joists are used between arches. Usually they are covered with sheathing and tar paper.

Hazards: This is determined by the size of lumber and the span of the arches. Most roofs of this type are well constructed.

SUMMERBELL

Description: This is an eggcrate or geometric designed arch roof which derives its strength from its entirety. It is constructed from good lumber, 2" x 14", steel plates and bolts at junctions, sheathing and roof covering. The arch is supported by exterior "buttresses" or internally by tie rods and turnbuckles. Common in gymnasiums.

Hazards: Possible total collapse of roof if fire starts to weaken or remove 2" x 14" sections. Collapse occurs from "domino" effect. One part goes, the rest follows.

GABLE ROOF

Description: "A" frame configuration. Conventional or ordinary construction consists of a ridge with rafters down to and across the outside walls. Ridge and rafters are usually 2" x 6" or larger. The roof will be constructed from semi-flat to steep pitches. Rafters are usually 16" to 24" on center.

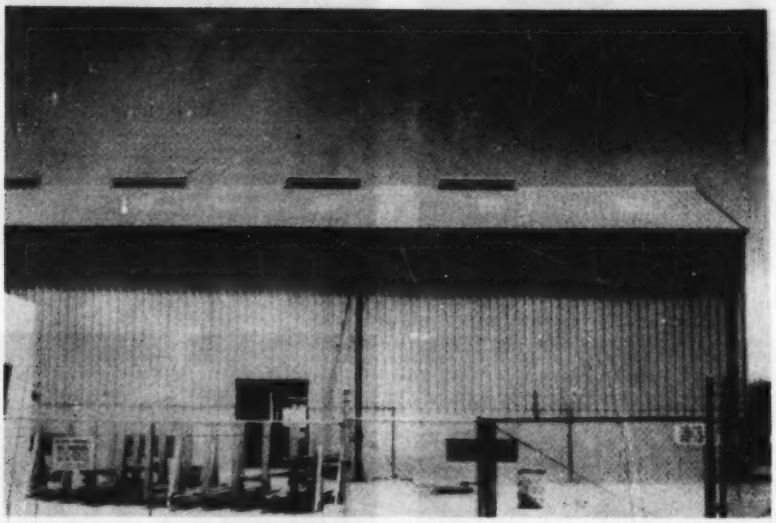
Hazards: Older gables may use 2" x 4" rafters. Newer roofs use 1/2" plywood as a covering instead of 1" x 4" or 1" x 6" stripping. The plywood will burn faster, offer little resistance to fire and is more difficult to pull off.

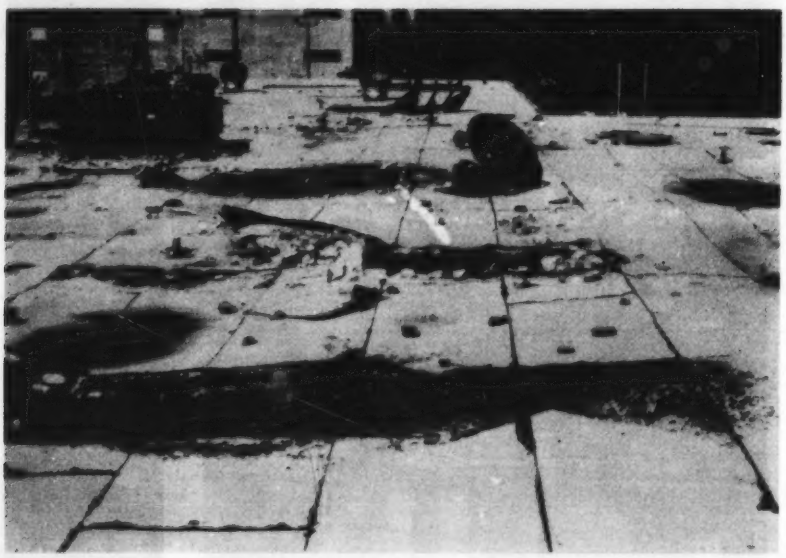
HIP ROOF

Description: Similar to gable, but no "A" frame configuration. The ends of the roof terminate in "Hip" configuration. Ridge, rafters, 2" x 6" or larger construction still present along with various types of pitches. Rafters are 16" to 24" on center.

Hazards: Newer type roofs use 1/2" plywood as a covering. Roofs with steep pitch will require a roof ladder to work from. If the roof is finished off with tile, it becomes extremely slippery when wet and offers no footing when dry.

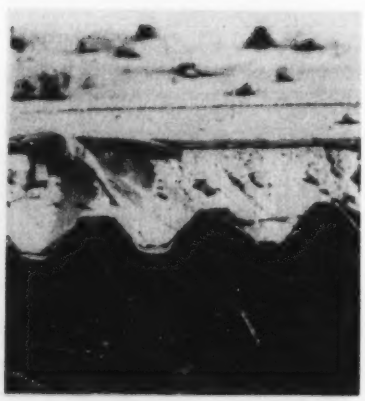
Corrugated Metal





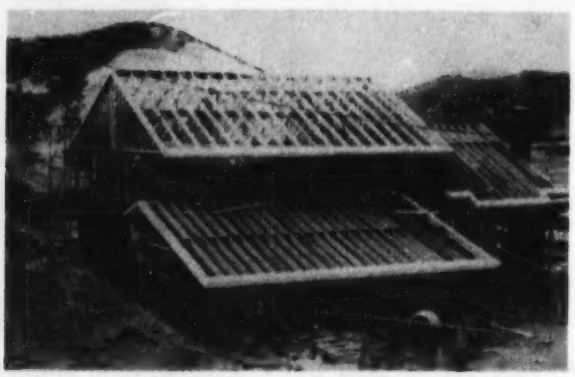
Summerbell

Light Weight Concrete

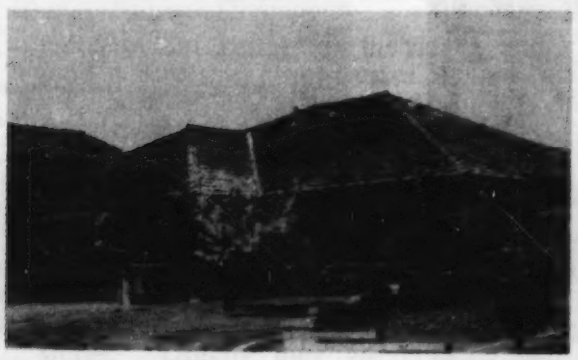


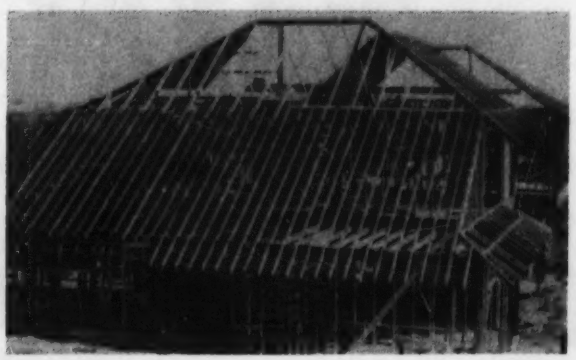
Conventional Flat Roof

Bridge Truss



Gable Roof

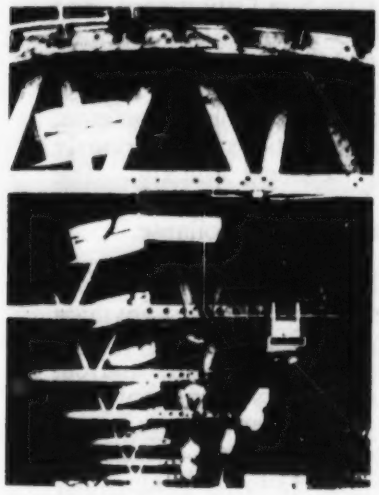


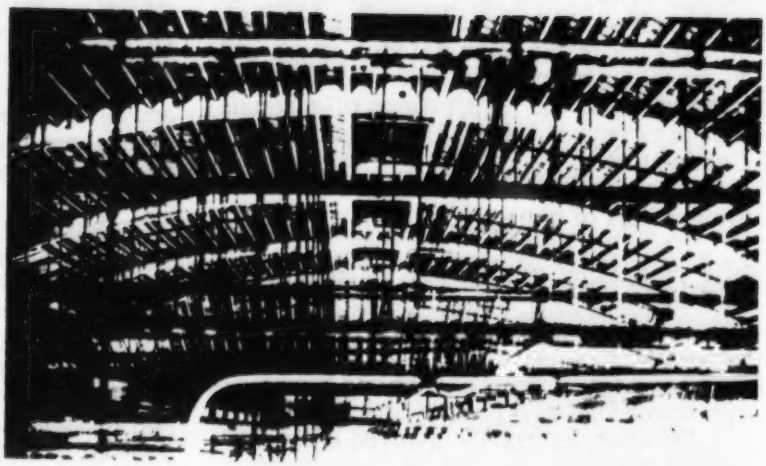


Hip Roof

Bowstring Arch →

Truss or Ribbed Arch





Recognizing the Probability of Building Collapse

Excerpted from Fire Engineering (February 1975)

BY FRANCIS CRUTHERS
Assistant Chief of Department
Borough Commander, Bronx
New York Fire Department

The possibility of structural collapse is of primary consideration in the development of strategy and tactics by the officer in command of a serious fire situation.

Were the factors leading to collapse simple, always evident and easily recognizable, the problems would be greatly minimized. We would then resort to an exterior attack and make our principal goals the protection of exposures and the maintenance of adequate distances between the building and the fire fighting forces.

Indications of collapse

The probability of collapse in commercial buildings is usually indicated when:

1. Two or more floors are fully involved in heavy fire,
2. Unprotected steel columns and beams are exposed to heavy fire, or
3. Occupancies heavily involved in fire contain machinery or supplies with a heavy weight concentration, such as plumbing supply houses.

There are few instances where the probability of collapse is so clear-cut as the conditions just described. In other situations, the proper decisions that lead to success rather than tragedy depend on the training and experience of the operating personnel, the recognition and transmittal of information about conditions, and the collating and evaluation of this data by the officer in command.

Residential problems

We in New York City formerly directed most of our concern about collapse to commercial buildings. Collapse of residential buildings was rare and was usually the result of a long-burning fire so that collapse could be anticipated and safety precautions could be established. However, in recent years vacant buildings, often residential, have become the most frequent scenes of collapse. The reasons for this may be summarized as follows:

Arson: While the vacant building fire problem has been with us for more than a decade, the extent and intensity of fire found by the New York City Fire Department upon arrival has been greatly magnified recently. Often three, four, and five floors of a 60 x 80-foot or larger building are involved. The use of accelerants such as gasoline is common, providing heat concentrations that seriously weaken structural members quickly. The weight of water from attacking streams is then often sufficient to induce collapse.

Looting: Recently vacated buildings are the targets of thieves who remove anything salvageable. Looters often cut floor beams, damage fire escapes, remove stairs and cut large holes in the floors and roof (for lowering salvageable material from upper floors). All of these detrimental "alterations" tend to affect the stability of a building.

Repeated fires: This is particularly perilous in partially tenanted buildings where vacant apartments are set afire accidentally by addicts and vagrants or by someone with a financial or political incentive.

Collapse traps fire fighters

The life hazard to occupants mandates an aggressive interior attack, search and rescue. This requires immediate feedback of information on stability conditions derived from the knowledge of previous fires and fire scene observations.

A recent fire in the Bronx in New York City

led to the collapse of a portion of the fire building. Seven fire fighters plunged from an upper floor to the first floor and several were seriously injured. This situation produced a rescue operation amidst the possibility of an additional collapse. A study of this fire incident provides insight into several phases of the overall problem of collapse.

Description of building

The fire was in a five-story, brick, 75 x 100-foot tenement building, erected in 1908, at 862 Jennings Street in the Bronx. There were five apartments per floor.

The building was at Intervale Avenue and Jennings Street. Three stores in this building fronted on Intervale Avenue, but are carried in the plans as part of the basement. (Jennings Street is a hill.) The building was actually six stories above the ground on Intervale Avenue.

The building was vacant except for one store and a bar at Intervale Avenue and Jennings Street. The adjoining store had a rolling steel door that was closed, indicating a current occupancy. Although the building was later determined to be vacant, almost all the windows were still glazed.

There had never been a serious fire in this building. However, since March 12, 1971, there had been nine fires at 862 Jennings Street, five with light damage to the building and four with no damage. This year there were two fires, both in the vacant store at 1379 Intervale Avenue. These fires occurred on May 6 and 7, and only one engine and ladder was used at each. There was no reason to suspect a lack of stability from the building's history or exterior observation.

Situation upon arrival

All three stores on Intervale Avenue were involved in fire this last time. Flames were showing at three windows on the second floor and one window on the third floor. A man was trapped at a top-floor window in line with the fire below. A woman, who probably had been patronizing the bar was screaming that her children were in the building. This was later proven to be false.

The rapidity of fire spread on the first floor was indicated by the fact that the owner of the bar fled the premises, leaving the cash register open and without removing the money. Burned paper money was found after operations were completed.

From the open lot at the rear of the building, flames could be seen on all floors in the outer court. The fire spread to the cockloft on the top left side of the building. Trenching prevented extension to the other side.

Due to the large amount of fire traffic at the time of this fire, response varied from the normal. Box 2739 was transmitted at 6:54 p.m., and a 10-75 was transmitted by Squad Engine 85 at 6:56 p.m. The deputy chief of Division 6 arrived at 7:00 p.m. and an all hands was transmitted at 7:03 p.m. The second alarm was transmitted at 7:04 p.m. (A dispatcher's third alarm was transmitted.)

Lines stretched inside

Operations consisted of lines stretched to the interior, lines operating in the stores, and a deluge set providing a water curtain on the second and third floor windows to cover the aerial removal of trapped citizens.

After all the occupants were removed and the extent of fire was reported to Deputy Chief Byrne of the 6th Division, all members were withdrawn from the building and heavy outside streams were placed on three sides.

When these streams had darkened down the main body of fire, they were shut down. An appraisal of conditions was made and at least twice, selective outside streams were used intermittently to extinguish pockets of fire that could be reached from the exterior. When it appeared that conditions had fully stabilized, units were returned to the interior via the stairs and fire escapes. These advances were made with deliberate caution under the supervision of battalion chiefs. Speed was not a consideration.

Floor collapses

Overhauling operations had proceeded for some time when suddenly an area above the center store, approximately 25 x 40 feet, running from Intervale Avenue to the interior public hall, collapsed. This occurred at 8:48 p.m. without any noise or warning, plunging seven members into a pile of rubble in the store below.

Byrne immediately ordered two additional rescue companies, two additional ambulances with doctors - or the disaster unit - fire department ambulances, clergymen, and an additional battalion chief. A battalion chief was ordered to continue with the fire extinguishment where necessary while another battalion chief supervised the rescue operations.

Two of the seven members caught in the collapse were near the top of the pile of rubble and were removed immediately. The remaining five were buried in the rubble and had to be found, dug out, and removed. Despite the unknown condition of the remainder of the building, the very real possibility of additional collapse, or at tleast the falling of dislodged material, members on the scene never hesitated. Members worked without respite until the seventh victim was removed at 10:11 p.m.

While several members received serious injuries, at the time of this writing all are on the road to recovery. Some members have already returned to some form of duty.

Signs of collapse present

The general attitude of all present was that the collapse was sudden, unanticipated, and without noise or warning. However, investigation revealed that there were several things known to different members which, if collated into a single data package, would have alerted the commander to the impending danger. Several of these items became known only seconds before the collapse, so time was not available for communication. The factors involved were:

Water on floors: Several members stated that water was ankle deep on the floor, particularly in the area that collapsed. Units were ordered to, and did, cut holes in the flooring to relieve the water situation. Runoff water is not usually a problem in multiple dwellings. However, the depth and area of the water in this instance (concentrated in the center of the floor) indicated a possible bowing of floor beams.

Holes in floors: Several officers found holes in the floor at the fifth and sixth floors. A number of them were large enough to prevent advance. While the holes were recognized and cautious tactics were used, their presence was not reported to the officer in command. A possible explanation for this is the repetitive operations that our members respond to in vacant buildings. They are aware of the holes normally found, but associate them more with injury from falling, rather than with the stability of the structure.

Sagging floors: One officer noted that the floors were sagging and had a wall opened at the beam ends to determine the amount of support. Finding only a half inch support, he continued examining beam ends prior to communicating this information to the chief. Moments later, the collapse occurred before the information could be relayed.

Sliding plaster and plaster dust: Another officer noticed large pieces of plaster "sliding" off the wall, and the presence of plaster dust clouds. He moved his unit to the safety of the interior stairway and was trying to contact the deputy chief by walkie-talkie when the collapse occurred.

Had most, or all, of these conditions been reported, they would have mandated a reassessment of conditions and might have led to the withdrawal of forces - at least to the interior public hall, which remained intact.

Victims must be identified

Concurrent with rescue operations, an immediate assessment of the number and identification, by name and unit, of all trapped members must be made. This is necessary to allow:

1. A determination as to how extensive the operation is, and the amount of assistance needed,
2. The pinpointing of an area where a victim might be located (using unit association), and
3. The discontinuance of search operations as soon as all known victims have been removed. With the possibility of further collapse, the importance of this should be self-evident.

The above can be accomplished by a roll call conducted in each unit and a report submitted to the commander. The riding list provides the most expeditious means of accomplishing this. The accuracy and presence of these riding lists at this particular operation provided the information needed within a reasonable time, long before all the victims were removed.

Maintaining riding list

It is, therefore, imperative that the riding list be kept up to date. Remember:

1. Only those men actually responding with the apparatus should be on the riding list. (This has no relation to roll call entries accounting for men scheduled to work that tour.)

2. The riding list must be maintained in legible condition. Often poor handwriting, or perspiration, makes the list difficult to read (even by the writer.)

3. The riding list must be constantly revised, covering such situations as when a member goes to the store, is detailed, acts as messenger, or in any way changes his riding status.

4. A copy of the riding list must be kept in the cab of the apparatus. This list must be available in the event the officer is one of the trapped victims.

Research is under way to develop a more practical method of maintaining an up-to-date, legible, easily available riding list.

Chance of second collapse

Perhaps the most pressing problem in an operation such as this is control. The chance of a second collapse is often very real and it could easily become a more tragic occurrence than the original collapse.

At this operation, the bravery, dedication, and skill of all members assisting in the rescue operation were beyond question. Observations on the scene, however, pointed to steps we could take to assure a safer and more coordinated operation.

The first few minutes after a collapse are minutes filled with trauma and confusion, even for the veteran fire fighter. Often those who have escaped injury in a collapse can't remember anything of their experience. They sometimes find themselves several buildings or hundreds of feet from their original position without knowing how they got there.

Others who have witnessed the collapse, seeing brother fire fighters or civilian victims within the rubble, rush headlong into the midst of the danger area without a plan or tools. Of course, their immediate thought is to extricate these victims. While there are times when this is necessary and productive (the victim is on top of the rubble, can be easily removed, and there is danger of another immediate collapse), most often an organized operation will produce the fastest, safest and most positive results.

Conducting rescue operations

The following procedures are offered:

1. Company officers should form their members into a unit, and operate as a unit. Do not allow men to wander and free-lance it.

2. Officers should supervise their unit, not engage in actual manual operations. Coordinating their men, observing the surrounding area for unsafe conditions, and rotating men to avoid fatigue will pay much greater dividends than adding one more "work unit" to the company.

3. Only the number of men actually needed should be permitted in the danger area.

4. If the particular assignment can be done by two or three men, the remaining members of the unit should be ordered outside the danger area and used for relief on a rotating basis.

5. If the assignment requires the entire unit, a relief unit should be assigned by the chief. These two units should rotate as units to avoid fatigue.

6. When the operations are lengthy (more than half an hour), rotation of personnel is mandatory. While perserverance and courage are noteworthy, this type of operation requires exceptional physical and mental input. Fatigue develops quickly, resulting in accidents, injuries and less productivity.

7. One unit (or battalion chief with unit) should be given the responsibility of keeping track of all victims leaving the scene. Assure positive identification. Record ambulance attendant's, or doctor's name. Assure definite hospital destination. Record any diagnosis of injury. Turn over all this information to the officer in command.

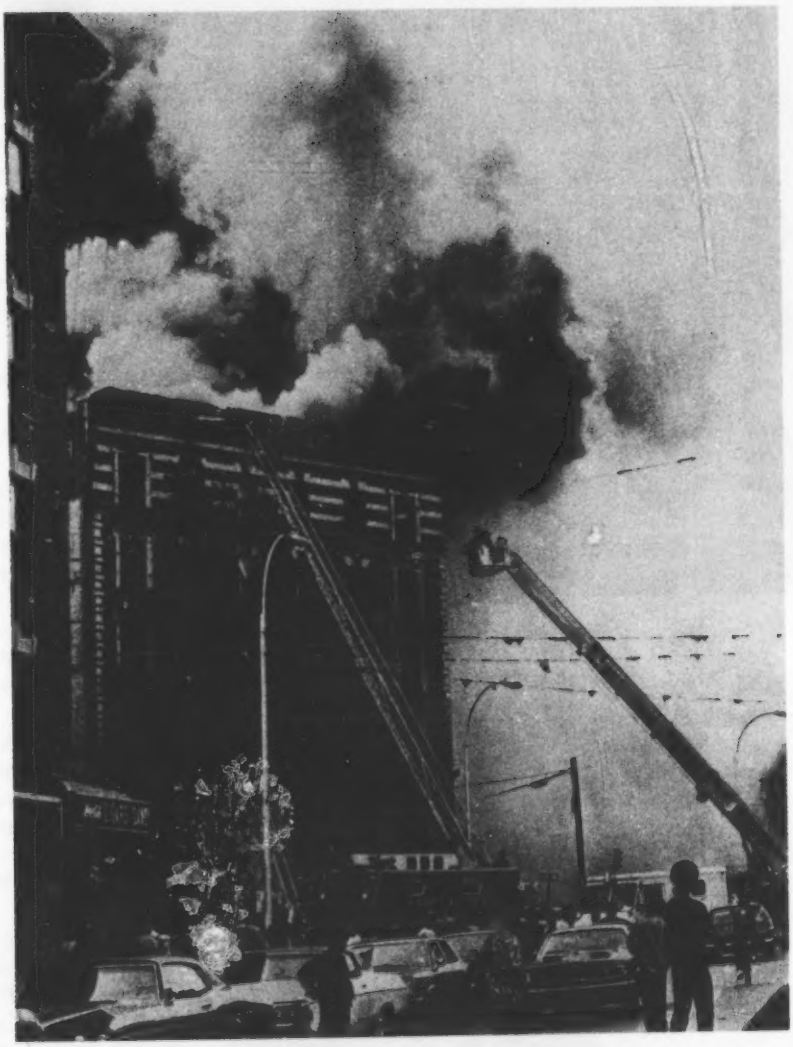
A fire department exists because things happen that are not supposed to happen. The way we respond to the unexpected and unusual is the measure of our success. It is the ability to look at our operations in retrospect that produces the fund of knowledge that marks the fire service as a profession.

Adapted from WNYF, Issue No. 3, 1974, official publication of the New York Fire Department.

Fire fighters tear apart rubble to reach trapped men— *FDNY photo, Biondi.*

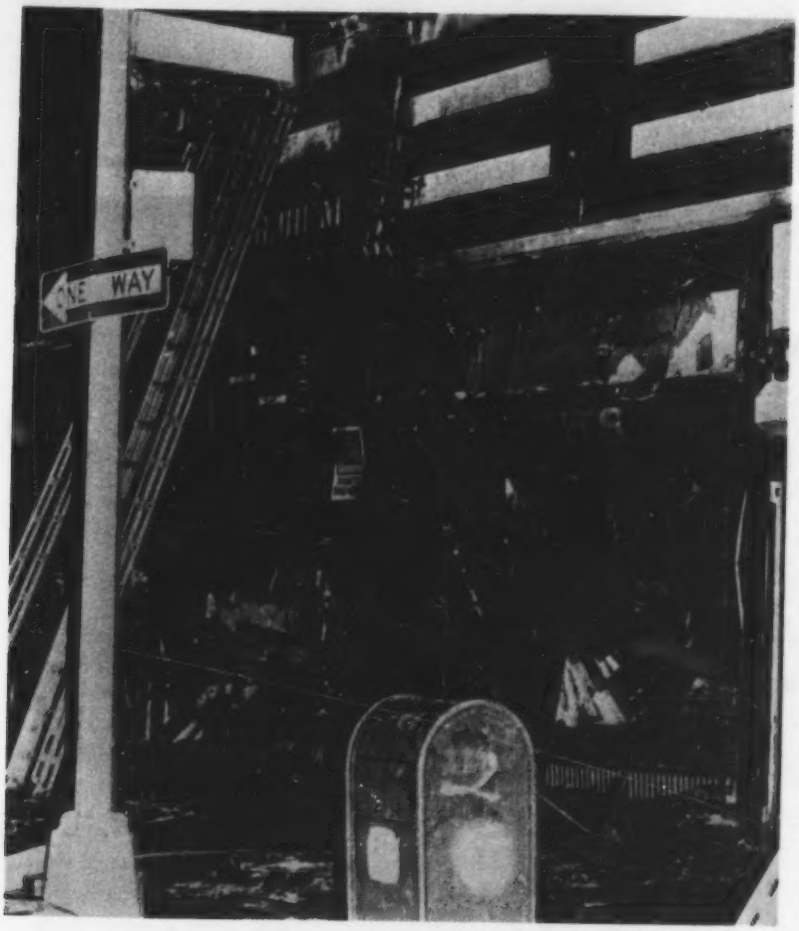
Photo by Vincent Ferrullo

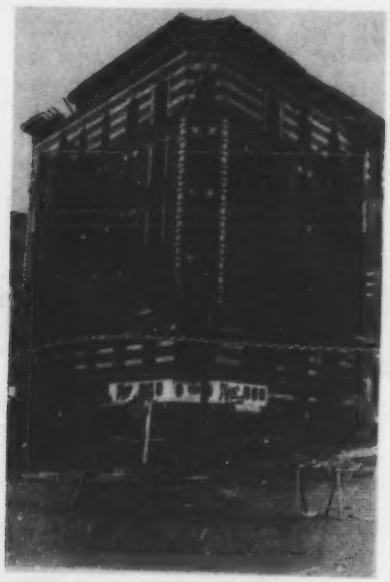
Fire fills all three stores in building as first-alarm companies begin lining in.



Aerial streams attack fire raging through tenement building in New York City where partial collapse trapped seven fire fighters— *photo by Michael Kosinenko.*

Debris fills store below area where collapse occurred— *photo by Michael Kosinenko.*





FDNY photo, Tufte

Exterior of building shows evidence of extent of fire that spread through all floors.

Planning Helps a Fire Department Cope With Chaos of Building Collapse

By Jerry Laughlin
Associate Editor

When a building collapses, the fire department gets the rescue call. It's the kind of incident that severely tests a department with a variety of factors to be considered and organized.

It could happen anywhere: in an existing modern structure, as with the recent Kansas City hotel walkway collapse; in a building under construction, as with the Cocoa Beach, Fla., incident described in this issue; or wherever there are tornadoes, earthquakes, explosions and fires.

The number of victims may be large but the exact number unknown. Some may be removed quickly with department equipment while others are trapped under massive structural elements, requiring specialized outside assistance. Suddenly hundreds of people may swarm to a collapse scene, making coordination especially important. Order must be brought out of chaos. Although easier said than done, the command post and critical communications must be established quickly.

The collapse may also involve fire, yet fire fighters cannot attack in the usual way because the rest of the area may be structurally unsafe.

Know authority

The absence of fire at a collapse scene introduces a possible legal question as well, according to Frank Brannigan, author of "Building Construction for the Fire Service." While the fire department's authority at a fire is usually clearly spelled out in the local law of every community, he reminds fire officers that "the authority to act or to direct others at emergencies other than fires is rarely defined." That matter, of course, should be worked out before- not during - an incident involving collapse.

One item helps more than anything else to bring order to the potential chaos of a building collapse incident: a plan.

Most departments have an overall disaster plan, according to a survey by the International Association of Fire Chiefs for the Federal Emergency Management Agency. It is not just a document for the fire department, but also for every other group that may become involved. Intermeshed with the overall disaster plan, however, is the department's specific plan locating and removing victims of a collapse. The operation may take as long as several days, but the steps are the same.

1. Survey the site.
2. Immediate care and removal of surface victims.
3. Searching for victims in voids and potential shelters in the debris.
4. Removal of selected debris.
5. General rubble removal.

Site survey

An initial size-up and survey of the site is similar to that of any major fire incident. The idea is to gain the information necessary for decisions on manpower, equipment required and techniques to be used. Any decision to call for outside equipment and personnel should be made as quickly as possible, with an understanding of the extra delay to be expected from crews not on standby and not trained in emergency response.

Although rescuers will want to begin operations as soon as possible, time must be taken during the site survey to consider safety requirements.

At a New York explosion and building collapse described in a recent issue of "WNYF" from which the five steps above were taken, one teetering wall was pulled down and another shored up before extensive operations could begin among the other debris. One fire fighter was assigned to

continually watch the shored wall to report any shifting. Even when shored, an unstable wall could be affected by the vibrations of heavy equipment.

Disrupted utilities

A building collapse almost always will result in ruptured electrical, gas, water and sewer lines. Although these items are normally the responsibility of utility companies, some situations may require action by rescue personnel. The disaster plan should instruct in the proper way to shut off utilities. Other hazards to trapped persons and fire department personnel may be gases used in refrigeration units and chemicals used in industrial operations.

Rescuers should assume that all downed electrical lines are "hot" unless known to be safe; energized wires do not always spark or indicate being live. Pools of water close to live wires may be just as dangerous as the wires.

Problems with broken sewers are not as quickly recognized as the problems with electricity and gas. Dams may have to be improvised to keep any flow away from victims and rescuers. Furthermore, the sewer gases can be explosive as well as toxic. Self-contained breathing apparatus should be worn.

Surface victims

While the officer completes the site survey and requests any outside assistance, visible victims can be removed from the danger area and given immediate care. If the located victim is partially trapped, aid may involve uncovering faces and supplying oxygen until complete removal is possible.

When the surface victims are removed the most difficult work at looking under the debris for other more seriously trapped victims begins. Directions of bystanders are often unreliable. This was the case at the New York collapse, for example. Better information may come from survivors or injured victims who were closer to the action and may have been near others during the collapse or immediately afterward. Bystanders and survivors, however, may be disoriented by the stress of the situation.

In Cocoa Beach, no one had a reliable list of how many workers were on the scene before that collapse. Even if a so-called accurate list is available, there is the possibility of mistake, unknown visitors or unauthorized trespassers at the time of the collapse. Some victims may be taken to hospitals before the arrival of aid. In fact there may be no one trapped after all, but the working assumption must be that others might be somewhere under the debris.

Looking for voids

Although the Cocoa Beach incident was a pancake collapse - flat layers stacked on top of each other - many incidents will produce a jumble of debris. When floors fall unevenly, lean-to or v-shaped voids are produced where victims may have survived. But the jumble is predictably unstable, and personnel should be kept off piles as much as possible during a search.

Tunneling may be required to reach some voids. Construction of tunnels and the all-important bracing is usually the work of outside specialists rather than fire department personnel. Tunneling is said in the book "Emergency Care and Rescue" to be one of the hardest jobs in rescue work, and it should be undertaken only when other methods are impractical.

The collapsed building may have a cellar with a sidewalk entrance. Then rescuers can enter and reach victims in voids perhaps faster than digging from above or tunneling. At the New York collapse, rescuers entering the dangerous cellar used SCBA and had lifelines attached.

Calling and listening

Sometimes conscious victims hidden in voids can be found with a coordinated "round-the-clock" hailing system, in which rescuers are arranged in a circle around the building or part of it. One rescuer after another (round the clock) calls out and then listens for any victim who can respond.

Coordinating the quiet listening periods is very important, but difficult. The high noise level of responding sirens, nearby pumping engines and other equipment made this method impossible at the New York incident.

Recognizing a body in debris is another difficulty. To avoid further injury to a

victim, tools should be used with great care. When close to a victim's possible location, debris removal should be with gloved hands.

Selected debris removal

Selected debris removal, to continue the search after all voids are checked, requires the heavy equipment. In New York the fire department recognized the importance of planning for the coordination of all assisting agencies, yet the recent incident reminded that all plans are altered by actual conditions.

In Cocoa Beach Chief Bob Walker is expanding his resource list of available equipment because of the complexity of such disasters. Kansas City, which handled its recent collapse admirably, has a 39-page catalog of metropolitan emergency resources that is updated annually. Of course, heavy equipment phone numbers are not enough; companies and operators, as well as other official agencies, must be consulted when a plan is devised.

Compensation

Often overlooked when emergency phone numbers are compiled are the arrangements to compensate for the use of expensive outside equipment. Agreements must be reached on a local level.

In Kansas City, outside companies are required to assist during the first 24 hours of an emergency without guarantee of payment if "public facilities are unable to arrest further damage to humans or property values nor reestablish an orderly physical environment..." If a disaster situation continues, equipment and operators may be required for another 48 hours, but payment is provided "at cost."

Many companies would be proud to be of assistance in an emergency and would not be concerned with payment, but this matter also should be discussed before an incident, not during.

Saying thanks

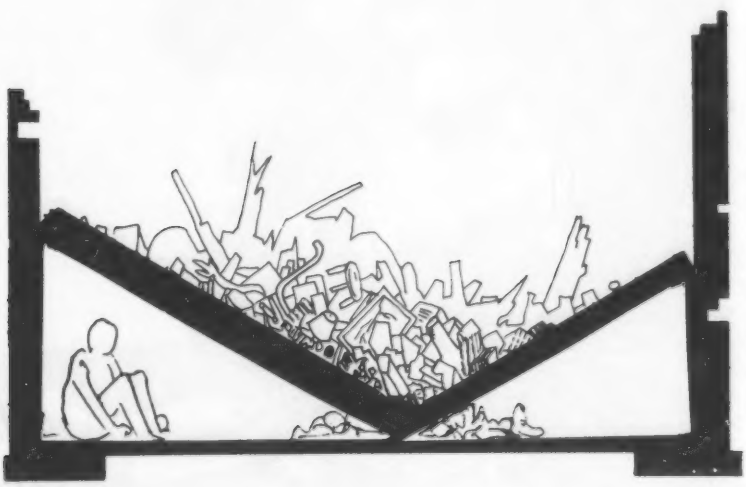
Regardless of any financial matters, fire department rescuers in Kansas City knew that they were grateful for the outside assistance so willingly provided. In a thoughtful gesture the department presented certificates of appreciation to those who participated from outside the department.

After selected debris has been removed and all likely voids checked for survivors, the odds for finding others alive decreases. Nevertheless, bodies must be found also. General rubble removal is then used when persons are still missing. This should not be confused with a general cleanup to clear a site for rebuilding. General rubble removal is a systematic part of the rescue operation and should be supervised accordingly. Miracle rescues can occur even when the situation seems hopeless.

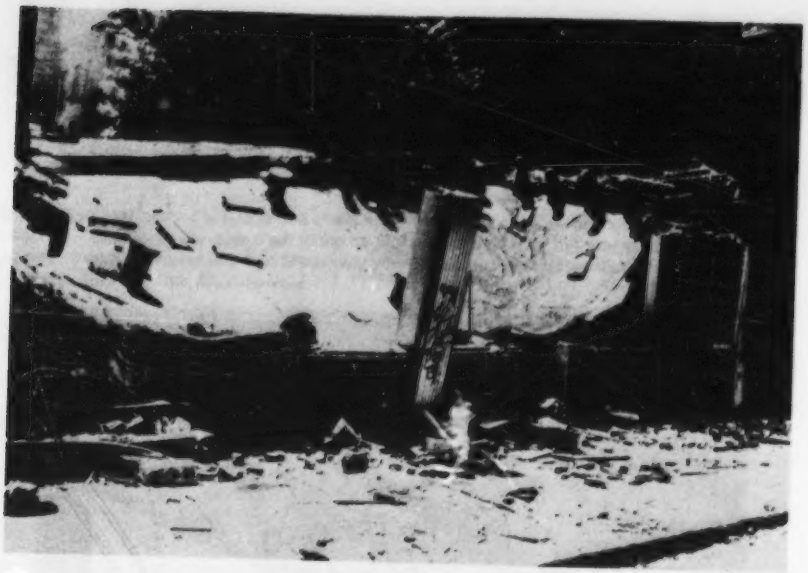
Soon after any collapse incident is declared over, a critique of the entire operation is in order. If parts of the plan worked extremely well they should be noted. But not every incident can be handled according to an untested plan. Use the new information gained from experience, while its impact is still fresh, to reshape the plan for next time.

Many rescuers may be on the scene of a collapse so an efficient rescue operation depends on coordination. Five-story elevator shaft in the background stands over the rubble of the Florida condominium under construction that previously was the same height (see next article).
Photo by Bob Cross, Orlando, Fla., Fire Department.

Survivors of a building collapse are often found in the voids formed when floors fall unevenly. This ia a lean-to void.



V-shaped void. Lean-to and V-shaped voids are often unstable, and rescuers should consider the condition of the debris they are working on and under.



New York Fire Department photo by Fireman A. Guerriera, courtesy WNYF

An unsupported lean-to lacks the propping effect of one side against the floor. The center area can be especially weak and dangerous.

Photo by David Handschuh, courtesy WNYF

Fire accompanied this New York explosion and collapse. Extra personnel and equipment are necessary to handle such an added challenge to an already difficult situation.

Fighting Fires in Taxpayer Buildings Raises Cockloft, Back Draft Problems

Excerpted from Fire Engineering

By William E. Clark

There is a type of store building found in most cities and towns across the country which can present several serious fire fighting problems. In many places it is called a "taxpayer" for a reason which gives a slight clue to the basic cause of the problems.

The name derives from a custom in the real estate investment business. An investor buys a piece of vacant commercial land which he expects will increase considerably in value over a period of years. In order to get enough income to pay the taxes on the property during the interim - and perhaps gain some profit from rents - he puts up a row of stores. This building is not meant to last a long time, and the owner wants it built as cheaply as possible. As a result, it usually ends up with structural and design features which the fire department should understand and be able to cope with during a fire. Some taxpayer fires can be quite dangerous to personnel as well as difficult to extinguish.

The foremost of these features is the common cockloft - the space between the top of the store ceilings and the underside of the roof. In some of these buildings it extends, undivided, over the entire row of stores. In others, there may be an occasional dividing wall, but because of weak construction or the presence of poke-through holes for pipes or cables, it cannot be depended upon to confine a fire.

Inasmuch as the partitions between stores may be flimsy and not fire-stopped, a fire may travel up into the cockloft where it will find plentiful fuel sources, and little or nothing to confine it. Because the cockloft space is large in area and often as high as 5 feet in the front of the building, it will have plenty of air at the start. In addition to the fuel supplied by wooden ceiling joists and hangers, roof joists, beams and boards, there will probably be a coating of combustible dust which will accelerate burning for a while. Of course, because electrical wiring travels through the cockloft, many fires originate in wiring and get a strong start before discovery.

Extension in cellars

While common cellars are not as frequently found as undivided cocklofts, they are not rare. Sometimes the division under the stores is no more than a wire fence from floor to ceiling. The fence may impede people (including fire fighters), but it won't stop the passage of the fire. In some taxpayer basements the partitions are made of wood, often with large spaces between the boards. They won't stop much smoke or heat, and will provide a lot of fuel arranged to ignite easily and burn rapidly. It is important to regard the whole row of stores as one large building in which the stores are merely rooms.

The cellar entrances vary from city to city, but are usually of three types: outside stairs (front, rear or both), inside stairs with full door at the top, and inside stairs with a trap door at the top. The inside stair with full door usually is next to the side partition of the store. It starts round the middle of the store and descends toward the rear of the basement. The trap door type is usually located near the back wall and descends at a steep angle. The top of each will be hard to find in dense smoke, and difficult to descend in face of much heat. The outside stairs are a blessing by comparison, but are still not an easy route if there is much fire in the cellar.

One of the few advantgaes for the fire fighters is that the buildings are not tall. Usually they are only one story in height, although some are two stories.

In most locations the exterior walls are of masonry construction, but occasionally wood frame is encountered. Roofs are flat, usually

the "built-up" or tar and gravel type on wood. They will burn readily and weaken quickly. Frequently there is a large skylight over each store in the one-story structures.

The occupancy of each store varies considerably. There are shoe stores, pharmacies, gift shops, beauty salons, etc. These stores and their basements can contain a large variety of combustible contents.

The life safety record of one-story taxpayers is excellent for the occupants but not for fire fighters, many of whom have died in such premises. The occupants of the one-story buildings usually escape easily from daytime fires and are not present at late-night fires.

Hazards to fire fighters

Fire fighters have been killed by a variety of causes. Some died from floor collapse due to heavy contents such as a baker's oven or commercial refrigeration equipment. Men on the store floor and men in the basement have been killed by this cause, sometimes simultaneously. Roof collapse has also taken a toll of men on the roof when it gave way. Falling walls do not occur often with this type building and are seldom a cause of death.

Back draft has caused fire fighter fatalities in one-story taxpayers in more ways than one. The large-volume cockloft provides a place for the products of combustion to build up to an explosive mixture, which if ignited will react with sufficient force to blow the ceiling down, or to push out a portion of the wall. Both of these have killed fire fighters.

There is the hazard of smoke, which can be guarded against by breathing apparatus, but in one case, fire fighters died of carbon monoxide accumulated in the basement which they returned to without breathing apparatus after the fire had been extinguished. There have also been cases of fire fighters trapped by a fast-spreading cellar fire, and even cases of drowning in the water from fire fighting in the cellar.

An action plan for fire in a one-story taxpayer would call for the following steps:

1. Find the fire. Just where within the structure is the fire burning? What way is it likely to spread? Can it be controlled easily or is there a good chance of it extending? These questions can be answered by the presence of visible flame or glow, or without that, by examining window glass by sight and touch for signs of heat. The concentration of smoke in a particular portion of the building could be an indicator, although it should be remembered that smoke may travel to one end of the building and bank up there, where its presence could be misleading.

In some cases fire in a partition or up in the cockloft can be detected by the sound of crackling.

Since further actions will be dependent upon the location and extension probability of the fire, it is important that these factors should be determined as soon as possible.

During this time hose lines can be made ready but not definitely committed until the fire has been found.

A crucial determination is whether or not the fire has entered the cockloft.

2. Ventilate. The roof is the key location for ventilation, not only to retard the fire spreading through the cockloft, but also to prevent back draft. If the fire is in the cockloft it will be drawn to a hole in the roof. Therefore it is essential that such a hole be cut as nearly over the seat of the fire as feasible. One large hole is better than several small ones. There is a quick way to ventilate a store and its cockloft. It is done by removing the skylight completely, and with a pike pole, open up the sides of the skylight hatch which wall it off from the cockloft. This not only provides a vent from the store, but also the cockloft.

The ground floor stores can be ventilated front and rear by opening the rear windows and breaking, if necessary, the show windows in the front. Sometimes just the removal of the transom glass is sufficient, but when conditions are severe enough to require breaking the big show windows, this step should be followed by removing any partitions at the back of the show window bench area.

Cellar ventilation can be quite difficult. Smoke ejectors may be helpful if they can be put in place. Taxpayer cellars are entirely below ground level, but some have window wells covered by gratings which have to be removed or spread wide enough for a tool to be inserted and break the window.

As ever, it should be remembered that not only will this ventilation accelerate the fire, but also draw it to the openings. This leads to the next consideration: having hose lines ready and in the right places when ventilation begins.

3. Placement of hose lines. If fire is found in the basement, steps must be taken to keep it from traveling upward or horizontally. If it is not too severe, the fire can best be confined by extinguishing it quickly with the first line taken directly into the basement and additional lines stretched to the points vulnerable to fire travel. Most of the time this is effective; however, if the sizeup indicates considerable fire progress, it may be well to position the first line to prevent upward fire extension and use the second line to attack the main fire. This tactic is especially useful when there are both interior and exterior basement stairs.

If the amount of heat and smoke is great at one cellar entrance, it may be far less at the other. Once I saw a company stymied on the front stairs when they could have made it easily down the back. The front stairway acted as an exhaust passage while the rear served as a path to the fresh air being drawn to the fire.

Many of these stores have no floor extending under the window bench. If the panel under the show window is removed, it can provide an opening directly into the cellar which can be used for ventilation or even the application of water.

The use of cellar nozzles through holes cut in the floor of the store is a last resort tactic as would be the use of high expansion foam, which may very well subdue the fire in the cellar but will not likely overtake fire that is spreading upward between the walls. Distributors may be effective in stopping the horizontal spread in the basement (and the cockloft, too). They can be left in place, operating unattended for safety's sake, if need be.

Every effort should be made to keep the fire out of the cockloft or, if it is already there, to arrest its spread. There have been many cases where fire fighters have pursued the fire from store to store, finally catching up to it at the end of the building. It may be necessary to go two or more stores ahead of the fire to make a stand that will stop it when it reaches that point. Although it takes moral courage to go into a perfectly whole store, as yet untouched by fire, and start pulling ceilings down, with adequate hose lines ready for when the fire reaches that position, this may be the only effective tactic.

Precautions

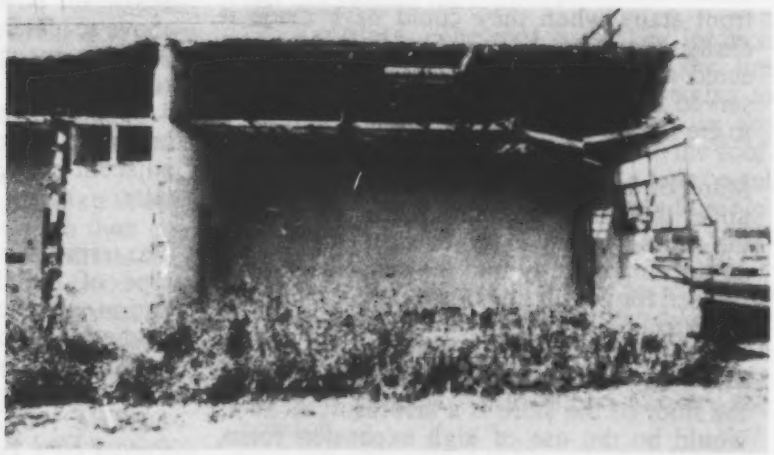
The following precautions must be taken in fighting taxpayer fires:

1. Where the occupancy indicates heavy floor loads, floors may collapse during basement fires.
2. Restaurants that use large amounts of gas for cooking might have a large gas leak due to melting at the big meter which would be present. Gas should be shut off in the street as soon as possible. Gas burning at the meter is not nearly as hazardous as the leaking of unburned gas. High expansion foam may extinguish burning gas, but it will not stop the leak which could cause an explosion later.
3. Before a hole is made in the ceiling - from below - it is well to open the cockloft from above to lessen the danger of back draft when there is an accumulation of smoke in the cockloft.
4. When a hole is cut in the roof it should not be made where it would endanger a taller adjacent building if fire broke through there later.

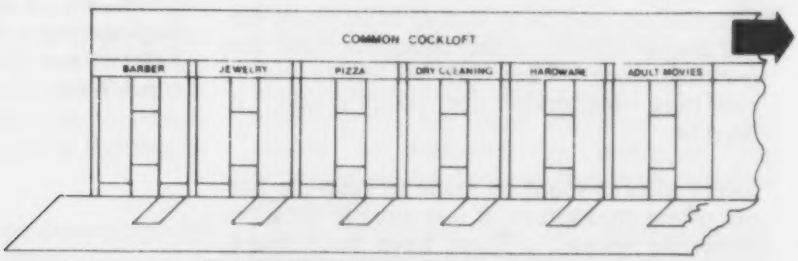
The term "taxpayer" may be regional, but this type of building is found throughout the nation. It is a building that deserves to be studied well in pre-fire surveys, and planned for accordingly.

THE AUTHOR: William E. Clark is a former New York City battalion chief. He is the author of "Fire Fighting Principles and Practices," published by Technical Publishing Company, publishers of Fire Engineering. He is presently living in St. Petersburg, Fla., and working as a fire consultant.

Taxpayer type of construction is exemplified by this block of stores.



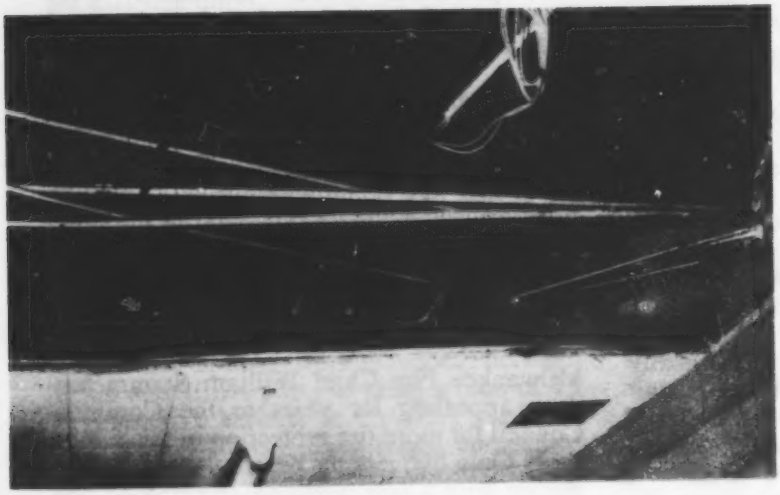
Cockloft area, space between roof and hanging ceiling, is visible in this unusual view.



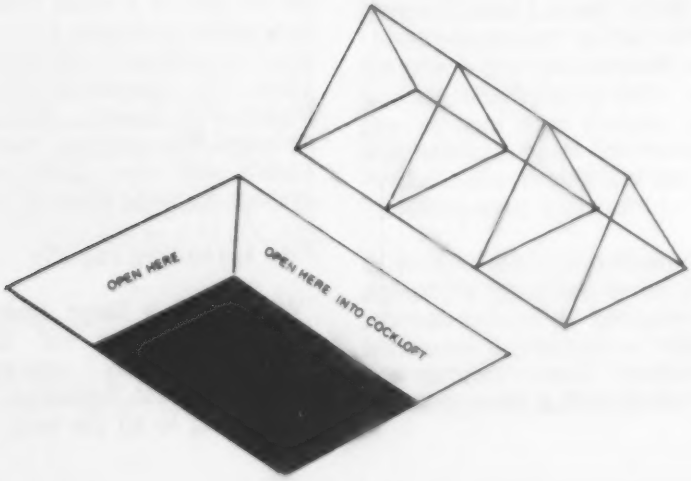
FRONT VIEW SHOWING COCKLOFT AND CELLAR DOORS

Modern taxpayers frequently have steel roof decks supported by unprotected steel bar joists, which can be expected to fail early in heavy fire conditions.

Cockloft is used for running electrical and telephone conduits, shown here, as well as for plumbing pipes and ductwork for heating and air-conditioning systems.



Steel roof decks of some taxpayers are supported by steel beams and girders.



Fire Feeds on Design Weakness

Excerpted from Fire Engineering - Nov 1976
By R. L. Nailen
Staff Correspondent

How fast fire can spread because of a single weakness in building design was dramatically shown by a $750,000, five-alarm blaze this summer in a Milwaukee condominium complex. More than a score of families safely fled the involved area. Many others carted out their possessions from units threatened by the racing flames.

Three factors prevented a conflagration:
1. Quick, resourceful, well-coordinated attack by fire fighters.
2. Lack of wind.
3. Buildings in close proximity only at their interconnected corners, with large open areas interspersed.

All units occupied

The Mill Valley Condominiums were built between 1971 and 1973 on 29 acres in Milwaukee's far northwestern corner at 119th Street and Appleton Avenue. Unlike a number of apartment complexes involved in large-loss fires in such cities as San Jose and Houston in recent years, Mill Valley was not still under construction. It did not include large areas of wood siding or wood shingle roofs, and its units were occupied.

All 12 of its building modules were basically of the same floor plan: two-story, 18-unit brick rectangles, 125 x 137 feet, containing two "apartments" (units with rooms straddling a dividing wall) at each corner, plus 10 narrower "row houses" along the four sides. All doors opened into a central courtyard (47 x 60 feet) or into passageways near each corner connecting that courtyard with the outside. An underground parking and storage area beneath each module was reached by a sunken driveway into one side of the structure and via stairs from the first-floor level at two of the corner passageways.

Modules were connected together in several groups, one such being Buildings 6 through 9 (see map). As required by local codes and decisions of state authorities - consulted because of questions about whether the modules should be classified throughout as "apartments" - there were three four-hour "fire wall" separations provided within each module, mostly of concrete block extending upward to the roof.

Unfortunately, that's where the walls ended - beneath the wooden roof deck. There were no parapets. Also, fire-stopping did not break up the 4 to 6-foot overhang beyond the brick walls of the wooden roof structure (see diagram). In that area, an open space of about 3 1/2 square feet in cross section extended entirely around each module. There were no cutoffs between modules at their interconnection. Furthermore, the soffit forming the lower surface of the overhang was perforated sheet aluminum with thousands of tiny holes admitting plenty of air to fan a fire within.

Shortly before noon on Sunday, August 1, a bright warm day with most tenants at home, the occupant of Apartment 5 in Building 7 near its juncture with Building 8 decided to solvent-clean some bicycle parts in his first-floor rooms. He then left the building - and the solvent container - for a short time. At 11:59, a number of phone calls reported fire in Apartment 5 to the Fire Alarm Office.

Milwaukee Fire Chief William Stamm has been appealing for years to the Common Council for more fire protection in this fringe area. Only two months before the fire, a new station with a new company (Engine 4) was put in service 2 miles from Mill Valley. A new ladder company (21) went in service at another northwest side location during 1972. These two companies were first-due at Mill Valley that Sunday. The initial assignment included four engines, two aerials, a rescue squad, and two chief officers, with an average response distance of nearly 4 miles.

Fire spreading rapidly

"We found a large body of fire in the northwest corner (of Building 7) and spreading rapidly," reported Chief Leroy Bach of the 7th Battalion. "We had quite a job getting to all the units to make sure the

occupants were safely out."

By that time, fire had mushroomed upstairs, fully involving the apartment of origin. It then pushed into the roof, along both sides of Building 7, and both west and north in Building 8.

Direct access to the inner sides of the burning units near the fire's origin was impossible because of the sunken basement driveway entrances without grade-level access to the courtyards nearby. The rear or west side of the modules themselves faced onto broad grassy slopes down to wooded park land, with no access roads at all.

Several hose lines were dragged into the basement garages, then up inner stairwells to get water into the courtyards. Other lines were laid around the ends of the building group to the west side, and Ladder 3 was driven over the lawns to a point behind Building 7, sinking to the wheel rims in the soft ground. Most operations had to be from the east side only.

Construction problems

There were no continuous balcony or hallway connections between units. While these can spread fire, they also provide places to make a stand - which the common roof spaces did not because of their inaccessibility. Fire in each unit had to be attacked separately, which from the courtyard side could be done only from the ground.

Additional alarms were sounded between 12:06 and 12:24 p.m., to bring a total of 15 engines, five aerials, an elevating platform, and special units. First-alarm companies were positioned to cut off extension of the blaze in four directions.

Reinforcements supplied more water, setting up three master streams to attack the main body of fire. Using 25 2-1/2-inch and 3-inch hose lines, 125 fire fighters brought the blaze under control at 1:27 p.m., but only after 20 dwelling units in Buildings 6, 7, and 8 were destroyed or damaged. Typical prices at Mill Valley ranged from $30,000 to $50,000 per unit.

Hydrants fully utilized

Water supply was fairly good. Almost all hydrants within reach were fully utilized. The main on 119th Street supplying these hydrants was fed by a 16-inch line along the south edge of the property, although near the city's extreme boundary there are a few cross-connections.

First companies were on the scene quickly, considering the response distance (three got there within seven minutes). Later arrivals were not all so fortunate. The last-in fifth alarm unit - Engine 5 - was preceded by a police escort, but still required more than five minutes to force its way through the last mile to the fire. Sightseers, drawn by black smoke visible for 30 miles, thronged the only two roads into the sparsely settled neighborhood. Chief Stamm himself could not get his car closer than two blocks away. Police from both Milwaukee and suburban Menomonee Falls, aided by sheriff's deputies, were unable to clear the area entirely.

Mill Valley was built according to plans that were filed with no local code violations. It is worth noting, however, that the Milwaukee Fire Department had never officially approved the plans - having lost that power when the fire prevention bureau was abolished by the Common Council in 1969, two years before the Mill Valley complex was begun.

Destructive overhang

Milwaukee building codes do not permit wooden shake or shingle roofs, which have contributed so much to conflagrations in residential areas elsewhere, but the horizontal flue provided by Mill Valley's roof overhang proved almost as destructive. Bach and Stamm were highly critical of this as well as of the roof boards bridging the fire walls.

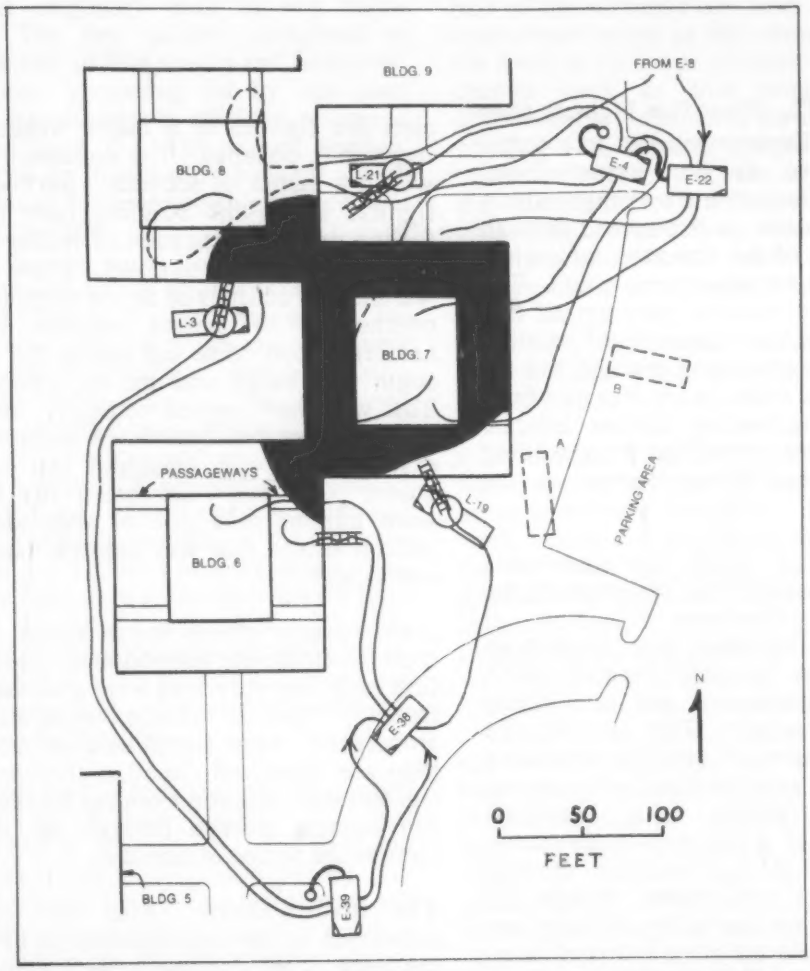
Said Stamm, "The design let melted aluminum and tar splash down on our men as they tried to work under the overhang to open it up and get water in there."

Bach and one fire fighter were hospitalized with burns, 10 other men received minor injuries.

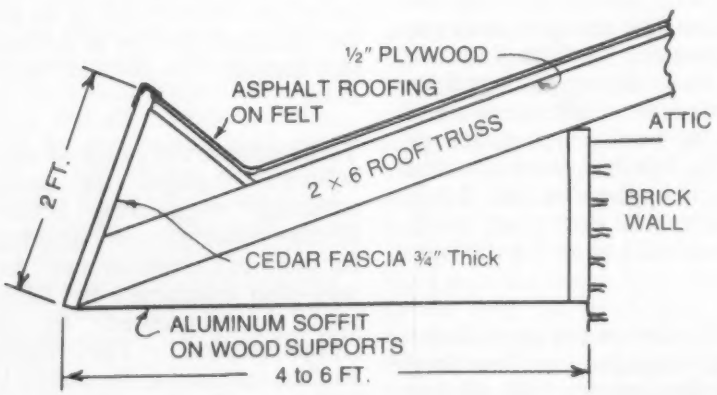
After launching a review of the building design the day after the fire "to see what went wrong" and saying "our ordinances may have to be strengthened," Building Department Deputy Inspector Leonard Sloane has since recommended a code change requiring 3-foot

parapets on future fire walls in similar developments. A final recommendation to the council by the Advisory Building Code Committee is pending.

Meanwhile, some 50 former Mill Valley tenants are starting over again, thankful that they escaped with their lives.



Map shows initial attack by first and second-alarm companies. Cross and arrows indicate fire origin and spread. Later, an aerial was positioned on lawn at A and an elevating platform at B. Dotted lines show hose pulled through basement garages to reach inner courts. Engine 38 acted as booster, making quick attack closest to fire with tank water supplemented by supply lines from next-due Engine 39 at hydrant.



Cross-section of roof overhang. Both soffit and fascia were supported on wood framing at 2-foot intervals. Similar fascia was attached to ridges, adding considerable fire load at peaks.

COLLAPSE OF THE HOTEL VENDOME

On June 17,1972, Nine Fire Fighters from the Boston Fire Department died in a partial building collapse at the former Hotel Vendome. The Department was engaged in a multiple-alarm battle as fire spread through the upper stories of the structure, which had been undergoing extensive renovation. The collapse occurred without warning; all five floors of the southeast corner of the building gave way. Eight men were rescued and the bodies of the nine others were removed from the rubble. Engineering studies indicate structural weaknesses resulting from building alterations as contributing factors in the collapse.

An alarm from a street fire alarm box summoned the Boston Fire Deparment to the former Hotel Vendome, located at Commonwealth Avenue and Dartmouth Street, at 2:35 pm Saturday, June 17, 1972. Three engine companies and two ladder companies responded. The 100-year-old structure of ordinary construction was being renovated for use as a combination apartment and shopping facility. A workman discovered the fire, which apparently started above the third floor, traveled through vertical openings, and vented through the roof in the center section of the building (see Figure 1). Four alarms were sounded as the fire progressed through the building. Master streams were used from aerial platforms, deck guns, and ladder pipes. The fire continued to burn under the roof and worked its way into the northeast corner of the five-story original section. Around 4:45 pm the rear southeast portion (the collapse area) was heavily involved between the fifth floor and the mansard-style roof. Heavy streams from two aerial platforms and a deck gun were in service in this area as the fire vented through the roof. After the fire had been knocked down, heavy-stream appliances and 2-1/2-inch hand lines were shut down and 1-1/2-inch hand lines were used to extinguish spot fires.

There were up to 20 men on the upper floors of the building, engaged in overhaul operations. At approximately 5:20 all five floors in a 40-by-45-foot section collapsed (see Figure 1). According to witnesses, none of the usual sounds were heard that would alert fire fighters of a major weakening or impending collapse. The collapse occurred within a matter of seconds. Surviving fire fighters inside the building later reported feeling only the sensation of falling as they rode the floor sections down. There were no warnings of ceilings or debris dropping from overhead. Witnesses outside reported hearing a loud noise and seeing the exterior south wall bulge near the third-floor level. That wall then toppled vertically, burying a new 100 foot aerial truck. A portion of the east exterior wall collapsed last (see the photo, page xx). Seventeen fire fighters were trapped in a pile of wall and floor section debris that was approximately two stories high.

Frantic rescue efforts began as fire fighters tried to release the trapped men. During the first hour four survivors were uncovered and freed. Special rescue apparatus and ambulances were summoned as additional help was organized. In all, eight injured fire fighters were rescued from the rubble. Grim fire fighters worked through the night to remove the bodies of nine men.

The investigation. After the fire, city authorities began investigations to determine the cause of the collapse as well as the cause and the origin of the fire. The investigations by the Boston Fire Department and the State Fire Marshal's Office failed to determine the cause of the fire. However, the area of origin was determined to be in a third-floor ceiling or on the fourth floor in an area adjacent to the collapsed portion of the building. All the fire damage was noted to be above the third floor.

To determine the cause of the collapse, city officials engaged the services of two structural engineering firms. Walter J. Hickey Associates conducted an investigation for the Fire Commissioner. An investigation was also conducted by Charles T. Main, Inc., as requested by the Building Commissioner. The findings of those studies, released to the public by the Mayor's Office on October 12,1972, are reported in this article.

The building known as the Vendome Hotel was originally built in two major sections. The first section, completed in 1872, consisted of five stories and basement. That section, measuring 64 by 104 feet, included the 40-foot-by-45-foot collapsed area (see Figure 1). The second section, consisting of six stories and basement, which extended along Commonwealth Avenue, was completed by 1880.

The first section was of ordinary construction with wood joists on brick bearing walls. The exterior walls in the north and east sides were faced with stone. The floors were wood on 2-by-12-inch wood joists. The hardwood floors were installed over tongue-and-groove sheathing on a tongue-and-groove subfloor. There was a mortar fill between the sheathing and the subfloor. The joists ran north and south and rested in pockets in the masonry walls with a 1-1/2-inch bearing depth. The joists were fire-cut to allow easy release from the walls. The roof consisted of a 7/8-inch-thick wood deck supported with wood joists. A leveling fill of concrete was later placed on the existing roofing and a wearing surface of quarry tile was installed.

The floors in the collapse area were originally supported by masonry walls at Lines A,B,C,D and E (Figure 1). The first and second floors were supported by all five walls. The third, fourth, and fifth floors and the roof were supported by interior walls at Lines A and C and by the exterior (south) wall, Line E.

Around 1890 alterations were made to the first story. That part of the bearing wall along Line C that was between the first and second floors was removed and dual 15-inch wrought iron beams together with a seven-inch cast iron column were installed. The beams and the column then carried the loads of the second floor and all the floors above, previously carried by the bearing wall (see Figures 1 and 2). The bearing wall along Line D, which carried the loads of the second floor, was also removed. That wall was replaced with 12-inch wrought iron beams suspended in a saddle on a 10-inch wrought iron beam that ran between the south exterior wall (Line E) and the dual 15-inch beams at Line C.

As a result of those renovations the seven-inch cast iron column became the main support of the bearing wall above the first story at Line C and also the main support of half of the second-floor load. Loading was now concentrated at one central point, with the areas to each side relieved of the load. A change such as this would encourage differential settlements in the pile foundation, which places strains on the bearing wall below the column. Evidence also indicates that the structural members of the new supporting system were not tied together. Bolted connections were not provided between the column cap plate and the dual 15-inch I beams. There were not ties between the column and the column base plate and no anchor bolts tying the base plate to the masonry wall.

After the hotel operations ceased, a project was approved to renovate the building for use as an apartment complex. The renovation work, which was in process up to the time of the fire, included significant alteration that affected the structural characteristics of the building. In 1972 a first-floor bearing wall at Line B, supporting loads of the second floor, was replaced with shoring. A portion of the first floor was also removed. Earlier, in 1971, a 12-by-30-inch sheet metal heating and ventilation duct was installed in the basement. That duct ran north and south and passed through the bearing wall at Line C below the seven-inch cast iron column (see Figure 2). The top of the duct was positioned 17 inches below the underside of the column base plate and the side of the duct was within five inches of the column center line. The opening in the bearing wall required for the duct was in a critical location and the base plate.

Conclusions. Both engineering reports concluded that the collapse began when the seven-inch cast iron column lost its support. This was caused by a failure of the masonry bearing wall under the column. Failure of the column caused failure of the masonry wall on Line C supporting the third, fourth and fifth stories and the roof, and as this wall dropped, floor joists were pulled from wall pockets along Line A and also from pockets along Line E (the south exterior wall). As the floor sections began to accumulate with other debris near the third-floor level, the lower portion of the south wall collapsed vertically. Partial collapse of the east exterior wall followed the collapse of the south wall. Figure 3 shows this sequence of collapse events.

The renovations had caused excessive stresses on the bearing wall under the cast iron column. Only a small additional increase was required to cause failure. As indicated by the findings of the investigating engineering firms, the collapse was due to a combination of three factors:

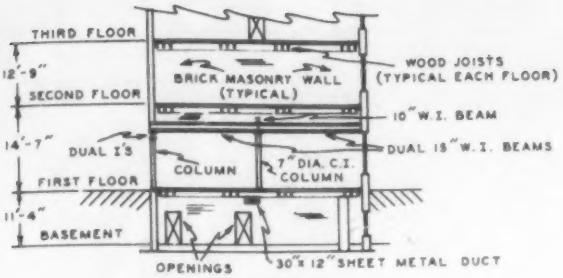
- Calculations indicate that the dead load on the column was about 200,000 pounds. The bearing stresses on the wall at Line C were seven to eight times the allowable stress for a masonry wall of a good grade of brick and mortar. Moreover, the mortar in the bearing wall was not in good condition.
- The addition of the heating and ventilation duct opening in an area of high stress under the column caused additional stress concentration. Investigators could not determine if a lintel of proper design had been installed above the opening.
- The addition of a live load could have been enough to trigger a collapse, given the above structural weaknesses. Fire-fighting operations apparently provided the live load.[1] Water also could have further deteriorated the mortar in the basement bearing wall supporting the column.

After public release of the two engineering reports, Boston's Mayor Kevin H. White requested a probe into the matter in an effort to improve procedures to be followed by engineers, architects, and contractors to avert a similar tragedy. Mayor White commented, "I believe that the preparation of technical plans for remodeling the Vendome and the technical supervision of the work while it was carried out were definitely inadequate." He added, "It is clear to me after reviewing these reports that this horrible loss of life could have and should have been prevented." The Mayor has also filed a proposal in the City Council requiring a registered architect or engineer to certify that the construction complies with the *Boston Building Code* and that the structure is considered safe and ready for occupancy. This proposal covers all multiple-occupancy buildings, which are to be reviewed and certified on an annual basis, and it applies as well to renovation and new construction projects.

This report by the NFPA Fire Record Department is based on information provided by the Boston Fire Department and the Mayor's Office, City of Boston. Building details and details concerning the collapse are contained in engineering reports by Walter J. Hickey Associates and Charles T. Main, Inc.

The photos on pages xx and xx are by Robert M. Currier. The photo on page xx is by UPI.

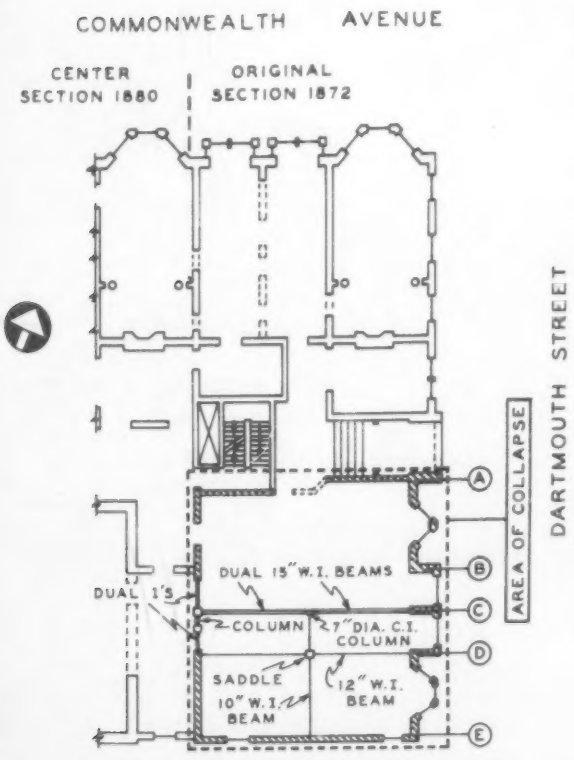
[1]The additional load could have included the weight of the fire fighters, equipment, and water from master streams and hose lines. See Francis L. Brannigan, Building Construction for the Fire Service: A fire Officer's Guide (Boston: NFPA, 1971) Chapters 2 and 4.



ELEVATION (LOOKING NORTH) OF BEARING WALL, LINE C

Figure 2

Sequence of collapse: (1) Bearing wall falls under cast iron column; (2) column falls into basement; (3) 15-inch dual *I* beams drop in center and rotate out of end bearings; (4) central wall (Line *C*) starts to drop; (5) when central wall drops two feet, floor systems slip free; (6) floor systems swing against walls, break free, and slide into basement; (7) floor systems lie against exterior wall (Line *E*); (8) lower portion of exterior wall gives way under pressure from floors, rotates outward, burying aerial truck; (9) and upper part of exterior wall collapses on top of debris. (10) Meanwhile, central wall has fallen into basement, along with fragments of roof.



SECOND FLOOR SUPPORT SYSTEM

Figure 1

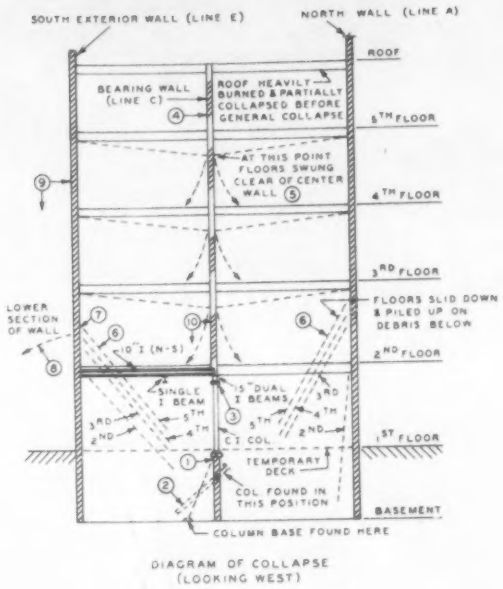
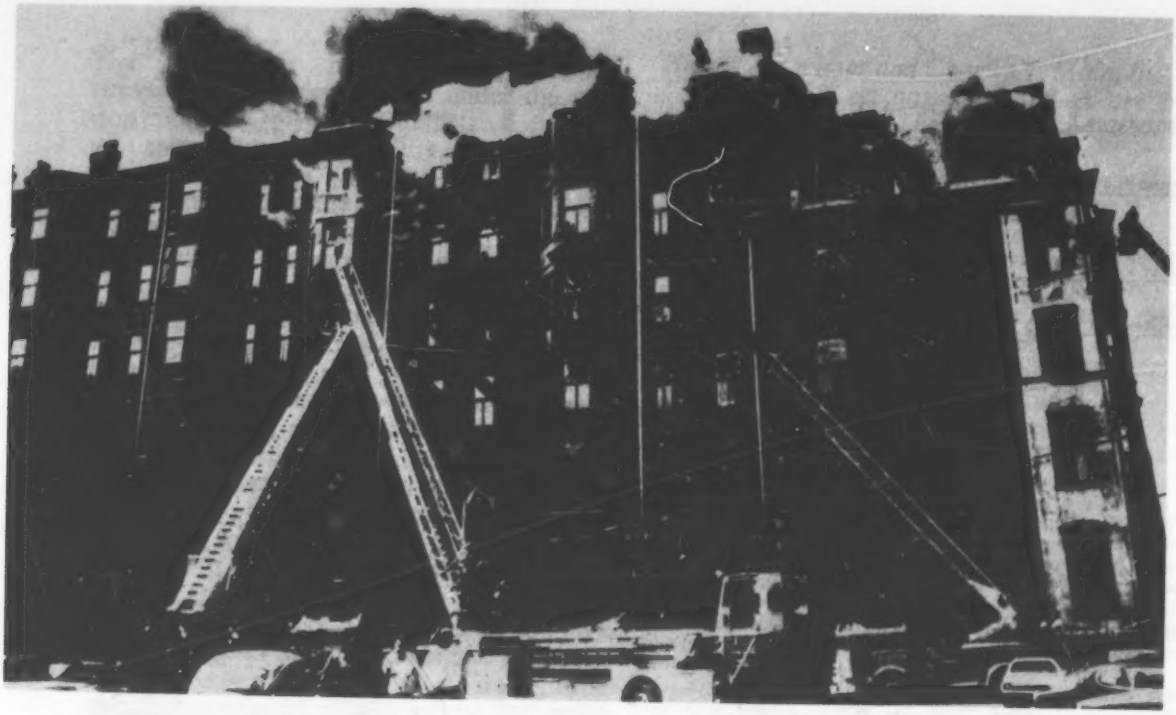


DIAGRAM OF COLLAPSE (LOOKING WEST)

Figure 3

Top: The first floor of the collapse area before the fire

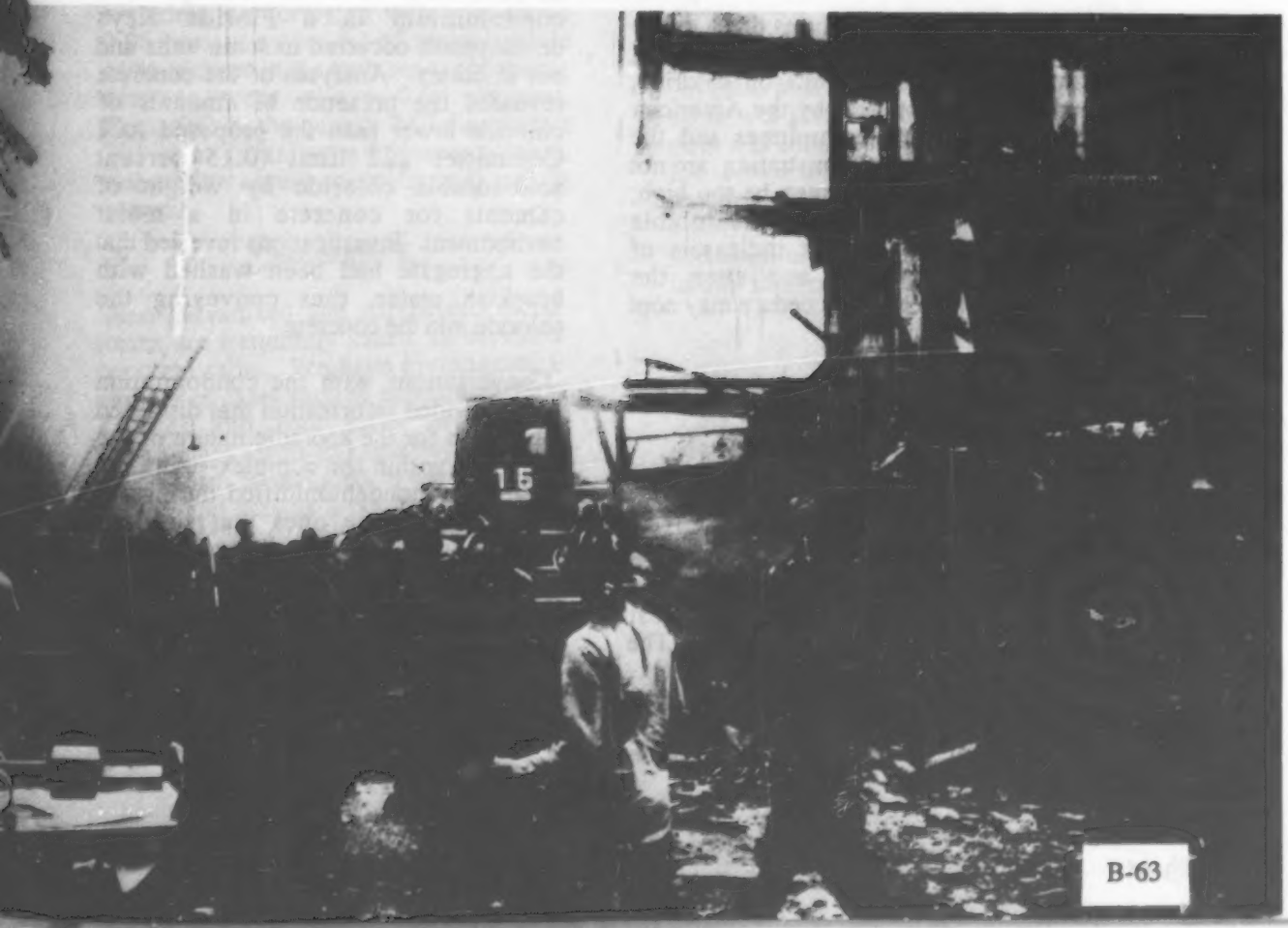
Above: This photo, taken before the fire, shows a heating duct piercing a basement masonry wall. A similar condition in the *C* Line bearing wall was a factor in this building collapse.



A view of the collapse from the rear of the building A. E. WILLEY

Left: The Vendome Hotel viewed from Commonwealth Avenue A. E. WILLEY
Above: The collapse area viewed from Dartmouth Street looking west

The photo below was taken moments after the collapse.
ROBERT M. CURRIER



Chloride-induced corrosion

Excerpted from Concrete International (September, 1985)

by Bernard Erlin and William Hime

A remarkable but disturbing event has occurred recently in the United States. Concrete engineers and corrosion scientists have become polarized with respect to both chloride limitations and the significance of water-soluble chloride determinations. Although admixture and chemical manufacturers are expectedly on the side of higher limits and the use of water-soluble data, many respected independent consultants occupy the same side of the aisle.

Yet our experience indicates that a totally opposite viewpoint should be taken, namely that present limits on chloride, such as those put forth by the American Concrete Institute committees and the Federal Highway Administration, are not too stringent and may even be too high; and that analysers for water-soluble chloride are insufficient indicators of corrosion portential, and even the prevalent acid-soluble procedure may nopt suffice in some instances.

The following examples illustrate some important facets of our thesis.

Case Study A

A proprietary latex sold as an admixture to greatly improve the strength of mortar and concrete has been found to do just that, but with a terrible side effect. The major active component of the latex, polyvinylidene chloride, breaks downs over a period of years in the alkaline environment of portland cement paste systems, liberating chloride ions that can cause corrosion of embedded or contacting metals such as iron and zinc (and thus galvanized steeel). Multi-story buildings have incurred over $10 million in damages because of this chloride-liberating process.

Case Study B

Corrosion of embedded steel chairs and reinforcing bars and of aluminum conduit in first floor concrete ceilings of a condominium in a Florida Keys development occurred in some units and not in others. Analyses of the concrete revealed the presence of amounts of chloride lower than the proposed ACI Committee 222 limit (0.15 percent acid-soluble chloride by weight of cement) for concrete in a moist environment. Investigations revealed that the aggregate had been washed with brackish water, thus conveying the chloride into the concrete.

Conversations with the condominium staff provided information that disclosed the reason for the sporadic nature of the corrosion within the complex--units left vacant and nondehumidified during the summer were the ones that suffered damage. A single exception was explained during a casual discussion with the maintenance man who, when asked for a possible explanation as to why the owner's vacant residence wasn't experiencing distress, volunteered that the condominium ceiling had an added 2 in. (51 mm) of cover over the steel.

Case Study C

As we noted in a prior paper on relationships between chloride and corrosion, the precast plank ceiling of an industrial plant after 70 years of staisfactory service suddenly began spalling, dropping pieces of concrete onto the floor far below (hard hats and fishnets quickly became the fashion while the investigations were carried out). Our studies showed that the acid-soluble chloride content of the concrete was few hundreths of a percent, and that carbonation of the alkaline cement paste had, after seven decades, finally reached the level of embedded reinforcing steel, permitting this low level of chloride to quickly lead to corrosion of the now depassivated steel.

Case Study D

Extensive investigations of corroding prestressing wire encaased in a mortar coat around one of two huge natural gas storage tanks revealed a significant difference relating to corrosion: determined water-soluble chloride contents of several samples from the tank experiencing corrosion were just above 0.06 percent by weight of cement, while none of those in the tank not experiencing distress were above 0.04 percent. Remarkable, the current ACI Committee 201 limit (possibly a concensus value, rather than a truly scientific one) is 0.06 percent.

Case Study E

Non-galvanized and galvanized metal forms are frequently usaed for elevated concrete salbs. We have investigated a number of cases such as elevated parking garages and roof slabs, where the left-in-place forms had severely corroded. If the form is included in the structural design and acts as a bottom reinforcing steel, the corrosion eliminates this bottom steel, and slab salvage by repair is virtually impossible. The chloride limit established for concrete with totally embedded steel is much too high for such systems.

Case Study F

Stressed steel of post-tensioned elements is vulnerable to corrosion in the presence of very small amounts of chloride in cases where the steel is loose in a sheath. For example, very small amounts of chloride can infiltrate grease used to fill the sheaths; the steel, lacking the passivation protection afforded by encasement in concrete, can then quickly corrode. Several examples of this situation have been reported.

Case Study G

We have found that chloride, even at levels deemed acceptable by ACI, has triggered corrision of reinforcing steel. For example, reinforcing steel in an on-grade concrete slab containing acceptable amounts of chloride had severely corroded, a probably result of a nonuniform moisture (and oxygen) distribution dsue in part to variable uptake of water from the subbase. A similar mechanism occurred in an elevated slab where water from a leaky roof saturated a portion of the slab.

In these instances, concentration cells set up in wet and dry concrete in which the steel was continuous were responsible for the corrosion. We have previously reported similar distress due to differential chloride concentrations that caused corrosion of reinforcing steel having 3.5 in. (89 mm) of concrete cover.

Conclusions

Our many studies of corrosion in portland cement systems, of which the above are only a few, have led us to the following conclusions:

READEX FICHE

1. Corrosion is not limited to bridge decks and parking garages. It is becoming an increasing problem in situations unrecognized by many investigators, and could become epidemic when much concrete containing the acceptable 1 to 2 percent calcium chloride by weight of cement attains middle age.

2. Water-soluble chloride concentration may relate to corrosion occurring at the time of analysis, but could bear no relationship to corrosion that occurred previously or can occur in the future. For example:

a. Initial chemically bound chloride in organic compounds may become unbound.

b. Relatively insoluble chloroaluminates created when chloride is present in fresh concrete may convert, with time and exposure, to sulfoaluminates and carboaluminates, releasing free chloride ion. Accordingly, acid-soluble chloridebalyses are needed to reveal the potential for future corrosion, and a total chlorine procedure may be required if a chlorine-containing organic component is present. The proposed ACI COmmittee 222 acid-soluble chloride requirements are a step in the right direction.

3. The present limits on chloride concentration are not too strigent. Indeed, for mortar, even the Brick Institute of America's admonishment that no chloride *be added* may be insufficient since shloride can also be introduced in appreciable amounts as comtaminants in any of the mortar components. Because mortars carbonate relatively rapidly, and thus lose their passivity-producing alkalinity, total chloride in the *mortar* should be restructed ti very low levels.

Because concrete aggregates have, in our experience, recently evidenced higher concentrations of chloride (due to deicing of aggregate stock pile and runoff of deicer salts from streets), restrictions applying only to added chloride may miss major sources.

4. A chloride concentration measured at a single location can be totally misleading, especially for concrete exposed to deicer salts. Concentration cells, created when embedded steel is present at different depths, or when chloride penetrates nonuniformly, can produce large corrosion currents.

5. The major factor triggering corrosion is usually the chloride concentration, but:

a. Water and oxygen are required, and thus environment and concrete quality (primarily porosity as affected by water-cement ratio of the paste) are significant; and

b. Carbonation can be the overriding factor, and therfore depth of cover is also important. The presence of carcks is significant, although controversy does exist as to the width of the crack necessary to lead to significant corrosion.

6. The usual rules for predicting or preventing corrosion are not applicable to metals not completely encased by concrete, such as decking and post-tensioning steel.

7. Some investigations to determine the causes for corrosion may simply require visual observation and a chloride determination, but others require a fuller arsenal of methods which may include:

a. Petrographic microscopy to determine depth of carbonation, water-cement ratio of paste, presence of corrosion-induced cracks, and development of secondary products indicating exposure to water.

b. X-ray diffractometry and spectrography to determine elements and compounds in corrosion products.

c. Infrared spectroscopy to determine the presence of organic chloride compounds.

Corrosion of metals in mortar and concrete in, unfortunately, not only here to stay but may enter a crisis stage as more and more ordinary structures undergo an untimely demise.

Appendix C

SUPPLEMENTARY READINGS

1. Building Construction for Fire Suppression Forces:
   PRINCIPLES, WOOD, AND ORDINARY CONSTRUCTION

2. Building Construction for Fire Suppression Forces:
   NON-COMBUSTIBLE AND FIRE-RESISTIVE CONSTRUCTION

SUPPLEMENTARY READING
PRINCIPLES, WOOD AND ORDINARY CONSTRUCTION

UNIT ONE: PRINCIPLES OF CONSTRUCTION

I. LOADS

A. Designed and Undesigned Loads

On the fire scene, firefighters have an urgent need for information about the fire building. If they need to ventilate the fire, will the roof hold their weight? If so, for how long? If they must enter the building, how strong is the structure? How close can the building be approached from the outside to avoid injury from falling building parts? Where is the building weak and likely to give way? In short, how much can the building be expected to take, and what can be done to keep it intact?

An approach that will assist the firefighter in safe operations begins with the concept of designed and undesigned loads. Building designers--we include architects and engineers--design a building to take the loads that are expected. They do not try to make a building invulnerable; no one could afford such a building. Instead, they try to calculate what weight the building will have to carry, given its intended use, and what outside forces will call for resistance. They do so by careful determinations based on the type of material they will use, the weight of the materials, and the shape or form in which they are used.

However, the difference between the building planned on paper and the building you confront in fire may be considerable. Did the builder carry out the plans exactly as written? Did occupancy change? What changes were caused when new equipment or HVAC systems were added or altered? When a building, or a part of a building, is subjected to forces greater than it can withstand failure may occur. The trained firefighter will focus on the "undesigned" loads in the building and recognize them as alarm signals. An inconsistency in the structure or materials from floor to floor (such as the absence of a bearing wall), new built-in equipment, or makeshift "patching" jobs in the support structure, tell the firefighter the building has been altered, and may not perform as designed. Further, building materials behave differently in fire than in ordinary circumstances, and the loads are typically calculated for materials operated on only by the normal thermal variations from season to season. A building which has ample strength to stand many years in normal circumstances may have fatal weaknesses to the assault of fire.

The design load of a building seldom provides for more than the minimum fire protection required by the code, and suppression forces must be at least as keenly aware of those requirements as their fire prevention counterparts.

Fire does not seem a likely occurrence to most building designers, and they are often reluctant to increase building cost. The fire protection measures which are instituted are predominantly focused on occupant safety and evacuation, not firefighter safety. For example, one book on structural systems notes that "fire resistance is not normally required in single story buildings because the people inside are already at ground level and can walk out of the building if a fire breaks out." Firefighters on the scene after everyone was expected to be gone must take note of this assumption.

It is the firefighter's job to know, for example, whether the design load for a roof may be as little as 30 pounds per square foot, or even less, in the given area. Few building designers are aware that firefighters commonly go to the roof to ventilate a fire, and today's lightweight roofs are often not designed for human weight. The results of sending a 250-pound firefighter to ventilate a roof designed to resist only a light snow load are quite predictable, and even more so when the roof is weakened by fire. The firefighter must be aware that his own weight might be an undesigned load the roof will not support.

B. Snow, Concentrated, Distributed and Wind Load

An important factor in the fire resistance and stability of buildings is the climate. Designers must strengthen buildings where hurricane-force winds, heavy snow, or unusual rainfall are expected, and that strength may give you more time in fire. It could also result in buildings with special characteristics that could influence their fire behavior. It is important for the firefighter to know how geographical characteristics have influenced building construction in the area, as this may be a definite asset or liability in a fire.

Firefighters must also take note of unusual weather events that may weaken buildings. When a fire occurs shortly after a particularly heavy snowfall, for example, firefighters should remember that the building may already have been pushed beyond its designed load and little can be expected from it.

A factor of safety is designed into the structure to allow leeway for unexpected stress, but a series of stressful events, a particularly difficult load, or a combination of circumstances may quickly exhaust the factor of safety. For example, if snow were to pile in one portion of the roof--posing a **concentrated** load rather than a **distributed** load--and if the concentrated load were near the newly added air conditioner, or the supports in the area were weaker than expected due to alterations or deterioration, there would be an excellent potential for roof collapse. It is therefore important to notice not just <u>what</u> the load is, but where it is and how it is applied.

A concentrated load may be indicated by a grillage (a series of closely spaced beams designed to carry a heavy load), a pilaster (a supporting pillar built into the wall, either on the exterior or interior of the building), reinforcement, or a change to stronger material. Firefighters should be attentive to these signals and try to identify and watch for concentrated loads overhead or where others are working.

C. Dead and Live Loads

In designing a building, the expected loading is divided into two categories for calculation: dead and live. The **dead** load is the weight of the building and any part of it that is attached or built in; that is, both the loads to be supported and the structural members that support them. Since the weight of the upper stories of a tall building must be supported on the lower stories, it is reasonable to expect more mass, and therefore probably more fire resistance, on the lower stories of such a building. Calculating the dead load of a building is a matter of multiplication-- the weight of the materials used times the volume of these materials,yielding a total weight.

Live loads are more tricky, and over the life of the building even more likely to change. Live loads are related to occupancy, and include persons and moveable equipment or furniture.

It may be anticipated that a large number of people will congregate in a certain area and very few in another, and the building will be so designed. But if room use varies and a room supposed to contain two desks becomes a storage room for heavy equipment, the shifting live load--even without the onset of fire--may spell trouble. For example, a broad suspended walkway that recently collapsed, killing and wounding many people, was carrying an unexpected, concentrated load of large numbers of dancers. (As it turned out, the walkway was in violation of the local building code--a reminder that what you're **supposed** to get is not necessarily what you've got. Unless, of course, **you** checked it out.)

Because an overloaded structural member will fail more quickly in a fire--and may not even require a fire to collapse--the firefighter must be ready to focus on the numerous loading situations within a building.

D. Fire Load

Fire load, like live load, is related to occupancy and affected by occupancy change. It includes all the parts or contents of a building that are combustible, and will therefore affect the number of BTU's involved. The interaction of fire load and other types of building loads may be a critical factor in fire stability. If a heavy fire load is located near a crucial supporting element or a concentrated load, for

example, failure may occur earlier than expected. Since areas where concentrated fire loads occur may shift, and occupants are unlikely to be aware of this factor, it is important for firefighters to know where fire loads are located and to predict their effect on the total response of the building to fire.

E. Static, Impact, and Suspended Loads

Suspended loads are also of obvious importance. The law of gravity acts instantly, and once the support for a load is gone, nothing will keep it in place even a second longer. It is the firefighter's business not only to identify suspended loads in buildings, but to identify what holds them up. Ceilings, light fixtures, and decorative elements may be supported on thin wire, possibly aluminum, and may fall, causing injury or death. The common suspended ceiling also provides a concealed void where fire can grow to tremendous size, releasing great heat as the wire ties fail and the ceiling drops.

Any falling load is an impact load--one that is in motion when it hits. Such a load hits with greater force depending on the distance it falls. A floor which can bear a given weight as a static weight may fail under the same exact weight applied as an impact load. **It is important to look not only at the fire, but up, and to inform others of the locations of significant suspended loads.**

Since visibility may be limited, such loads should be noted in information filed on the building.

F. Axial, Eccentric, and Torsional Loads

The placement of a load in relation to the supporting element may also affect stability. An axial load is straight and true, and supported by the center of mass of the supporting element. Such a load is the easiest to support, which is why columns are generally built exactly on top of each other. An eccentric load, which is off-center, has a definite disadvantage. From the fire service point of view, the more **bearing surface**, the better; for as bearing surface is decreased, the amount of material which has to burn through before failure is lessened.

Consider, for example, a joist used to support a floor. The builder orders precut material, which turns out to be a little short, since the walls are slightly further apart than expected--but not enough to matter, he feels sure. The wood shrinks slightly with age and use, and a heavy load causes it to deflect (bend). By the time a fire occurs, very little of the joist is actually bearing on the wall.

A load that causes an element to twist is called a torsional load. If a fixed element is struck by another falling element, it may twist, until its connection weakens and gives. If a theater marquee loses one of two suspending cables, it will twist. Few elements are designed to resist such a load, so it should be of particular concern to firefighters.

II. FORCES AND MATERIALS

A. Forces

A building may appear to have little to do but sit still. Actually, however, a structure is energetically engaged in resisting forces. As long as they remain in balance, the structure stands--but when the balance is lost, it topples. Building members are subjected to **compressive**, "squeezing" force, which causes them to buckle or crush; to **tensile**, pulling or stretching force, which causes them to become taut, then snap; and **shear** force, which causes the element's components to give and slide past each other. With practice, you will be able to identify the type of force a part of the building is designed to resist, what failure mode to anticipate, and where the structure is vulnerable. For example, where joists are tied together, the connection is crucial, since a shear reaction will be most likely at that point. Shear failure may be associated with either tension or compression.

B. Strength of Common Building Materials

Building materials may be divided into those that are brittle and those that are ductile. **Brittle** materials, which include brick, stone, cast iron, and concrete, are all strong in compression but weak in tension and shear. That is why columns and walls, but not beams, can be constructed of these materials. A characteristic of these materials is that they give little warning of failure, but crack or snap suddenly and absolutely.

Ductile materials, of which steel is the prime example, will deform before failure under ordinary conditions. If a load is in the **elastic range** of the member, it will resume its previous shape with no loss of strength. If it is in the **plastic range**, the member will be permanently deformed but may continue to bear the load. Unfortunately the excellent factor of warning is often not available to the firefighter, for steel also loses structural strength at temperatures which may be reached very early in a fire (1,100° is generally considered critical, but lightweight steel members may fail at much lower temperatures. Cold drawn steel, used in elevator cables, may fail at only 800°). In addition, steel expands, often adding to collapse potential. A 50' long steel beam, heated evenly, will try to expand by nearly 4 inches, which may be sufficient to move a wall, dislodge an adjacent member, or create an eccentrically loaded column.

C. Steel and Concrete as a Combination

To enable concrete to span a distance, steel is added to provide tensile strength. It is crucial for the firefighter to recognize that if the reinforcing rods are exposed, failure may be expected. Equally critical is the phenomenon of pre- and post-stressed concrete, which contains taut steel under tremendous pressure. The steel used in this concrete, like cast iron and unlike structural or reinforcing steel, has a high carbon content. Consequently, it has little elastic or plastic range. Further, it will not regain its strength once heated beyond its capacity, or give warning of impending failure by deformation.

It is especially dangerous in buildings in construction where heat may reach unsealed tendons. The following excerpt from Cowan's Structural Systems should serve as a warning against breaching a wall or cutting through a roof or floor which may be of this type:

> The demolition of prestressed concrete is unlike that of other structural materials. The prestress remains locked in the structure, and this can amount to a force of hundreds of tons. If the tendons are cut inadvertently with an oxyacetylene torch during demolition, the anchorages could be released and hit other parts of the structure, and perhaps people, with devastating force.

III. STRUCTURAL ELEMENTS

A. Variables in the Fire Stability of Columns

The fire stability of a column is determined by several variables.

One, of course, is **material**. An analysis of the strengths and weaknesses of the various building materials will determine their ability to serve as columns. For example, unprotected steel will be heat–sensitive and likely to buckle, while the coating on "fireproof" steel may be removed by hose streams.

A second variable is **connection**. A bolted connection is probably the most secure; a nailed or screwed connection less so; and a "gravity fit"--no connectors--is the least secure, and is vulnerable to any lateral impact.

The **height** of the column and its **slenderness** are also critical. Height decreases carrying ability, which is why intermediate **bracing** may be present for very tall columns (if it is, it is essential for stability). Slenderness is also related to instability, and a thin column is much more apt to buckle. Columns are sometimes H–shaped to reduce the potential of buckling.

Load-carrying capacity is also related to the **distance** of material **from the center**. Assuming the same thickness of material in the column shell, the wider the dimensions of the column, the greater the load-carrying capacity. It is important that hollow columns be closed at the ends so that they do not provide channels for fire spread.

B. Variables in the Fire Stability of Beams

There are several variables to be considered in evaluating the fire stability of beams.

One key variable is **depth**. The deeper the beam, the greater the load-carrying capacity. A second is the type of **support**. A beam supported at three or more points is called a **continuous** beam, which has a definite advantage--if one support fails, the additional supports will "share" the load, probably buying enough time for a quick exit.

A **cantilever** beam, which is supported at only one end, is a special concern. Many canopies at shopping centers are cantilevered, and their collapse has caused injuries and death, as well as the destruction of firefighting equipment. It is important to stay well away from cantilevered elements and take careful note of fire spreading in their support system. A collapse zone the length of the cantilever has been shown to be inadequate, as cantilevers may bring down the wall with them.

It is also important to watch for the creation of **undesigned** cantilevers. In high winds or sectional fire, for example, one support for a **fixed** beam (a beam connected at each end) may be destroyed. The resulting beam may fall under its own weight and trigger collapse. A "propped cantilever" may rely on an unprotected steel column, and a "suspended cantilever" (such as a typical theater marquee) may rely on relatively thin wire for its support and are unlikely to remain in place when it fails.

The **shape** of a beam may also be important to its stability. The **web**, the center portion of the beam which connects the two **flanges**, primarily resists shear forces. The flanges resist bending. Because the "neutral plane" in the middle of a beam does little work in resisting forces it may be removed, forming the "I–beam."

Recently, wooden I–beams with plywood webs have been developed. Once fire attacks the plywood web, or the plywood delaminates, the beams will collapse. The loss of mass from a regular wood beam to an I–beam obviously causes fire resistance to deteriorate rapidly.

The manner in which beams are laid is yet another factor. Laid flat as planks for a floor, beams have much less load-bearing capacity than the same beams turned up, since this provides more depth.

C. The Fire Behavior of the Truss

The truss is beloved of modern builders because it allows depth--and therefore greater carrying capacity--without mass, which is expensive. It is less beloved by the fire service, however. The efficient truss, with its lightweight members, is an interdependent structure from which no part may be safely removed. It presents an entirely different situation from a series of beams, in which the loss of one beam does not necessarily result in the loss of the others. The loss of one part of a truss throws the entire structure out of balance, and failure is probable.

Because the truss is made of members that have less mass, it is less fire resistant. Further, trusses are often made of a mixture of materials which spell trouble in fire, and may have connections liable to fail quickly. For example, metal gusset plates depend for stability on the penetration of tiny prongs, which will push away from attached wood quickly in fire.

D. The Arch

The arch is one of the oldest of structural forms. Early arches were of masonry. However, modern arches can be concrete, steel, or wood. Arches are frequently used for long spans where a high clear floor space is desired, e.g., sports arenas and armories. They can also be used for architectural effects such as church windows. Often arches have the shape of a circular segment or segments, but may also be parabolic, elliptical, or "flat."

Like the truss, the components of an arch are interdependent. Devised as a means of spanning distances with elements weak in tensile strength, such as stone, the arch depends for stability on **uniform loading** and the absence of tensile strain on its pieces. It is therefore important not to cut through an arch, including flat arches or tile arch floors of the type found in many older buildings.

Any connection points on an arch are critical to watch. They should be located in advance and analyzed for needed protection. In a masonry arch, the joints are probable breaking points and should be carefully inspected. Further, masonry support at the sides of the arch or tie rods must be recognized as important to stability, since the end of an arch tends to "push out."

E. Skeletal Frame Buildings

Looking at a building during construction, one quickly has a sense of what is critical to the support of the building structure, though not necessarily to the support of all the loads to be added later. At this stage the building may appear as a frame or skeleton, into which panel walls will be set or which will be built into the walls; or, it may appear as walls of masonry material. In the "bearing wall" building, the condition of the walls is a prime concern in overall building support, while in the frame-supported structure the elements of the skeleton are vital to stability.

F. Wall Bearing Structures

The way structural elements interact with each other under stress is largely determined by the joints. There are two basic types of joints: the **rigid** joint and the **pinned** joint.

In the rigid joint, members cannot rotate and bending may be transferred from one member to the other. Rigid joints are commonly created in poured-in-place-concrete, laminated wood, or welded or bolted steel. A pinned joint is just the opposite; if overloaded, one member will break off at the connection without

sharing its load; and the other member will not bend. Rigid frame action may exist in only one plane or dimension of a building or throughout the structure.

To the firefighter, a **rigid frame** structure--one that uses rigid joints--is a mixed blessing. In stress, a member will "share its troubles" with adjacent members and all rigidly attached elements will pull the load together. On the other hand, a limited failure of one or two elements is not possible; all the rigidly attached elements may be expected to go together.

In a rigid frame building, the joints typically bear the greatest stress and their condition is critical to stability. In a rigid frame gabled building, for example, the wall and roof frame supports are a unit and joined by a single joint at the top . If the joint fails, the whole building is liable to collapse.

IV. ROOF STRUCTURES

A. Types of Roofing and Associated Hazards

Roofing materials may add significantly to firefighting hazards and operational problems. The **built–up roof**, which is made of alternating layers of asphalt and felt, will produce dense smoke that may conceal signs of failure or skylights. If the roof is laid over a plywood deck, early failure should be expected. If the deck is steel, other concerns are noted: gas from the asphalt will seep through the joints and flames will roll beneath the roof as deep as 3 feet and destroy its support.

Other roofing materials pose a variety of hazards: **slate and tile** are heavy and sharp as falling objects, and slick to walk on; **metal** melts, and will cause serious burns without appropriate protection; **wood shingles** pose fire-spread hazards because of the tendency to form flying brands. The **corrugated roof** is supported only at the joint and is likely to fail rapidly. Furthermore, fiberglass skylights are common--one more way to fall through.

Thin membrane roofing has recently been developed which may be applied in tin sheet or liquid form. It may be made of a variety of components, and is likely to melt and/or be toxic. If this roofing is used in your area, it should be carefully investigated.

Even a **concrete** roof is not necessarily safe, for roofs are commonly much thinner than floors, and often not intended to support the concentrated load of a human as opposed to the distributed load of a little rain or snow. In some light concrete roofs, straw or other materials not likely to add load-carrying ability when stress is applied are used to provide tensile strength. Remember, too, that concrete is brittle and may give you no warning before it fails.

Many firefighters have been injured or killed falling through skylights or light wells. It is best to locate skylights before the fire, since smoke may obscure visibility. If a skylight is removed for ventilating, it should be turned upside down as a warning to other

firefighters. In any case, remember to sound ahead of your path as a matter of habit, and make sure others are directed to do the same.

B. Analysis of Roof Support Systems

Any new roof in your area may pose a slightly different problem than one you already know. Perhaps the connections are a different type. Perhaps this one uses a new combination of materials, or has an unfamiliar shape. It is important to be able to mentally break down each roof into component parts and analyze potential fire problems, regardless of whether you have ever seen one exactly like it. For each roof, certain key questions must be asked.

The **connections** are a vulnerable point and will usually fail first, so they deserve careful inspection. Metal connections used with wood are a special concern. They rely on friction, which is lost as wood heats and carbonizes.

It is important to determine the support beneath the roof support. If it is a wall, how much bearing surface is provided? The rain roof, built over a leaky roof, may have little structural support and is unlikely to carry weight. Tilt–up construction is a special case, since the **walls** depend on the **roof** to keep them in place. If the roof fails, the building is lost.

Looking at a roof in construction, it is not difficult to determine **strong and weak points**. Their spacing must be noted and become a matter of record. In the finished building, it is harder to tell. Firefighters can learn through practice to sound for key structural elements, however.

The **shape** and **configuration** of the roof is also a key point, as severe slopes or unusual configuration may lead to loss of balance, falling, and other safety problems. For example, on a sawtooth roof, a firefighter may climb over a wall to fall 6-8' to the roof's lowest point.

C. Roof Interdependence

The **interdependence** of the roof structure is a key factor, since it may mean the difference between partial or total collapse. Are parts of the support structure performing similar or different tasks? If one segment fails, how are the rest affected? To answer these questions you will need to visualize the removal of a segment and determine the reaction, based on your analysis of the location and type of connections present.

The **materials** are obviously a key concern. Mass increases fire resistance, and a slender member may fail quickly. Toxic or flammable vapors and gases should be considered. In a panelized

roof, insulation may be ignited and drop, spreading fire and possibly causing injury.

The **combustibility** of roofs is an old and very serious problem. Combustible roofs have been responsible for many conflagrations through their ignitability and production of flaming brands. Such conflagrations have recently occurred, for example, in Houston, Texas (1978) and Anaheim, California (1982).

A standard test exists to measure the relative combustibility of roof coverings when subjected to external fire; ASTM-E-108, Fire Test of Roof Coverings. The test method includes submission of samples of the roof covering measuring 40" x 52" to an intermittent flame exposure test, a burning brand test, a flying brand test, and a rain test. Test samples 13 feet long are subjected to a spread of flame test.

The burning brand test consists of exposing the roof covering to three sizes of flaming wood brands measuring as follows:

For class A	12" X	12" X	2-1/4"
For class B	6" X	6" X	2-1/4"
For class C	1-1/2" X	1-1/2" X	25/32"

To pass this portion of the test the roof covering must prevent ignition of the wood deck underneath the covering, must not produce flaming brands of the roof covering material, and must remain in place when exposed to the class A, B, or C wood brands.

As a result of testing, roof coverings are classed as A, B, or C with class A as the best.

- **Class A** materials provide protection against severe fire exposure presented by intermittent flame and burning brands, remain in place, and will not create flaming brands.

- **Class B** materials provide protection against moderate fire exposure, remain in place, and do not create flaming brands.

- **Class C** materials provide protection against light fire exposure, remain in place, and will not create flaming brands.

Representative materials for each class (according to the Building Material Directory compiled by Underwriters Laboratories) include:

Class A - Asbestos Cement Shingles
Asphalt Mineral Wool-Felt Shingles (grit surfaced)
Asphalt Organic-Felt Shingles (grit surfaced)
Asphalt Glass-Fiber Mat Shingles (grit surfaced)

Class B - Asbestos-Cement Shingles
Asphalt Organic Felt Shingles (grit surfaced)
Fire Retardant Treated Red Cedar Shingle and Shake Covering (factory treated and provided with .002" polyethylene coated steel foil)
Formed Steel Tile Covering

Class C - Asphalt Organic-Felt Shingles (grit surfaced)
Asphalt Organic-Felt Sheet Covering (grit surfaced)
Fire Retardant Treated Red Cedar Shingles
White Cedar Shingles, and Red Cedar Shingles
Panel Covering (factory treated)
Aluminum Shingle Covering
Molded Reinforced Plastic Shingles
(reinforced with glass fibers)

D. Safety Precautions

To prevent accidents in roof ventilation, the following cautions should be standard:

1. Sound ahead for safe footing.
2. Sound for structural strong points.
3. Never cut through a structural support.
4. Always have two ladders per roof so alternate escape route is provided.
5. Assign a minimum of two persons to ventilate.
6. Ascertain roof construction type.

V. FIRE RESISTANCE FACTORS IN FLOORS

A. Wood Floor on Wood Subfloor Supported by Joists

In heavy timber buildings, both a wood floor and a subfloor may be present. This floor is likely to be thick and relatively fire resistant, especially if bridging of the same size as the joist is used and will check fire spread. In addition, a layer of gypsum board or asbestos paper may be found between floors, further increasing fire stability. If bridging is not present, it is possible that joists will twist and become unstable.

B. Wood Subfloor on Wood Joist

This common floor is much less fire resistant because of its lesser mass. The redundancy between subfloor and floor is lost. The finish materials, which range from noncombustible to highly combustible, may be important factors in fire spread and stability.

A common type of floor in modern residences and light commercial occupancies uses a plywood subfloor on wood joist with finish flooring. The substitution of plywood ordinarily means less mass and, of course, less inherent fire resistance. It is important that the plywood is installed in accordance with the span rating noted on the third line of the trademark. A rating of 32/16 means that, used as **roof decking**, the panel would require on-center supports every 32 inches. As a **sub-floor**, however, it requires those supports every 16 inches.

C. Heavy Wood Subfloor on Wood or Steel I-Beams, Bar Joist, or Trusses

For such a floor, common in factories, warehouses, or other heavily loaded buildings, the relation of fire resistance to mass is the main thing to remember. If steel I–beams are used, ascertain whether they are protected, and if so, how. Spray–on fireproof coatings, for example, are often even easier to scrape off, and membrane fire protection must be complete to be effective.

VI. HAZARDS ASSOCIATED WITH CEILINGS

A. Ceilings

For the firefighter, it is important to develop a habit of looking up. It can save your life. Yet, in the urgent push to extinguish the fire, or the tiredness of the salvage and overhaul stage, it is too easy to forget the features of the building and their implications for safety.

What is most immediately overhead--the ceiling--is of special importance. Though it is not always thought of as such, **a dry wall ceiling** is a suspended load, nailed directly to the joist. When water accumulates on its surface, the nails may give.

A **plaster ceiling** is applied over a lath of metal in today's structures, but in older structures a wood lath was used, with predictable results--early failure. In some instances a lightweight metal lath may be nailed to furring strips rather than the joists themselves, providing a void for rapid fire spread. **Acoustical tile** is also applied to furring strips rather than the joist, so a void may be assumed. Types range from fire retardant to highly flammable.

Metal ceilings may be found in some older buildings, and may not be easily identified in a fire if painted over. Falling, burning paint may be your first warning of the presence of this ceiling. If you see it, leave quickly--sheets of hot metal will soon be falling also.

UNIT TWO: WOOD CONSTRUCTION

A. Variables in the Fire Performance of Wood

Between the fire performance of a heavy timber and light wood frame building, or a building with deteriorated wood and one with wood in top shape, lies a world of difference. In predicting a building's fire performance, the following variables must be considered.

1. **Surface to mass ratio.** In a heavy timber building--one in which the smallest dimension of a wood member is 8 inches--a protective layer of charcoal will form, retarding burning. Such buildings, commonly known as "mill construction," provided much more time for interior attack than most modern buildings, and may contribute to fire service overconfidence in newer structures.

In dealing with wood, mass is the key element--solid mass, not the amount showing on the surface of a hollow member.

2. **Condition of wood.** Inspecting a wood building, a blow may reveal that termites or dry rot have robbed it of structural strength. Be alert to a whitish color which indicates advanced state of decay. Decay is caused by microscopic plants, and develops when there are mild temperatures, sufficient oxygen, and moisture in the wood in excess of 20%. "Dry rot" is a misnomer, since it also may be traced to a moisture problem, without which the fungi that cause the rot cannot function. A yellowish or greenish color, on the other hand, tells you the wood is new and not up to full structural strength. Such wood will shrink as moisture is removed, increasing the eccentricity of floors and causing other problems in fit.

3. **Age.** New wood (unseasoned lumber) is fuzzy, and yellowish or greenish in color. It should not be confused with lumber treated with water–borne preservatives. It has more moisture than seasoned wood and may be expected to shrink. If introduced into a structure it may increase the eccentricity of the floor load on the wall or cause other problems.

4. **Lamination.** Laminated structural members show no difference in performance from regular wood. Plywood ordinarily does not delaminate water, as it is made with waterproof or water-resistant glue.

5. **Chemically treated wood.** Not all chemically treated wood is fire retardant. Some treatments only protect wood from insect infestation. The effect of fire-retardant treatment is to slow the rate of combustion. The treatment is only on the outside of the wood, however, and once it is consumed the wood will burn rapidly. The retardant chemicals are mineral salts--ammonium phosphate, ammonium sulfate, and boric acid--so the wood cannot be used outside; moisture would cause the salts to "leach" to the surface.

Ordinary preservative treatments may be water-borne, oil-borne, or creosote-petroleum mixtures.

Water–borne preservatives are commonly used to treat lumber and plywood because they leave the wood clean, odorless, and easy to paint. They give the wood a greenish-yellow tinge and do not affect fire growth. **Oil–borne** preservatives are applied to lumber for any use, except where lumber is in contact with salt water, and do tend to increase fire growth. This type of treatment may be recognized by an oily coating, brownish color, and smell. **Creosote–petroleum mixtures** are used for wood in contact with the ground. Some types are used in salt water installations. This treatment also increases fire growth, and may be recognized by an oily texture and pungent, offensive smell.

6. **Finish**. Finish materials can add both toxicity and flammability. Printed plywood is made by a photographic process which uses highly toxic materials. Often, high gloss finishes are more flammable, but this cannot be ascertained by appearance alone.

7. **Defects** can affect wood strength. Knots are restricted in lumber grading according to size and location, and can depreciate the strength of structural members. Shakes, lengthwise separations between growth rings in lumber, tend to reduce shear resistance, as do checks, which are separations across growth rings. Splits (lengthwise separations) may be serious defects, depending on the length of the split. A wand--the presence of bark or absence of wood--is also considered a defect, and may be found at the edge or corner of a piece of wood.
(I-21)

The **shape** of wood grain is also an important consideration. To calculate the slope, compare the average line of fiber direction with the horizontal, forming an angle. From a horizontal perspective, the wider the angle, the more severe the defect. The more parallel the grain structure to the long dimension of the wood, the stronger the material. When fibers are <u>not</u> parallel to the horizontal edge, the result is "cross grain lumber," which is weaker and may also cause warpage, end shrinkage, and torn or lifted grain.

8. **Loading** is also a consideration. Where warped or deformed wood is subjected to a heavy load, expect double trouble double quick.

9. **Polyurethane imitation wood** is of concern because of the highly toxic products of combustion: hydrogencyanide, carbon monoxide, and nitrogen oxide. In some cases it may mislead you in your analysis of a building because of its close resemblance to structural wood.

B. Connection Methods

Connection methods may be divided into four main types. One, **adhesion**, has already been discussed; your concern here is the adhesive--is it resistant to fire and water? A second is **connection**, in which a projecting part of one member is inserted into a hole or groove in the other. Here, your concern is the amount of wood making the connection and the quality (primarily tightness) of the fit.

Such joints generally have poor fire records, especially the mortise and tenon joints used in post and frame (an older and relatively rare type of wood construction not covered in this unit. For discussion, see Frank Brannigan's book). **Locking**, in which movement is prevented by the linking of members, is infrequently found. Where it is used, inspection concerns are the same as for connection. **Fastening**, in which connecting elements are inserted through the members to be joined, is by far the commonest method, and includes gusset plates, dog irons, staples, power-actuated fastenings, and nails, applied by hammer or "nail guns." Toe nailing, in which nails are driven at an angle through one member and into another, is not satisfactory for heavy stress situations.

Heavy gusset plates may help a great deal, depending on the amount of material used and the depth of penetration. For all such connections, the material used is a key concern (will it melt, or fall away early in the fire?), as is the **depth** of the connection.

In inspecting connections, you need to ask the same pointed questions in any situation: how much material has been removed; what is really doing the work of connecting; if underlying support is provided, how much material is bearing on the supporting surface; and finally, what will happen to all parts of this connection in fire?

C. Wood Framing Systems

In construction, it is easy enough to discover the framing system used in a given building. When it is finished, it may only be apparent from the basement or attic, or by opening the wall. The framing system is important in predicting fire response.

The **post and beam** system uses rigidly connected posts (vertical members) and beams (horizontal members) giving it the rigid character discussed earlier. Proper connections are critical to stability. It is commonly used with plank and beam floors since the wood surface is usually exposed, the finish may be a critical element in fire spread, and a huge volume of fire is possible.

Both **balloon frame** and **platform frame** are **stud framing** systems. The balloon frame is a particular problem because of the fact that continuous studs run from cellar to attic, accompanied by channels for vertical fire spread (check for presence and adequacy of firestopping from the basement). This means rapid collapse may occur once fire enters these channels, and a simple basement fire may suddenly appear in the attic, possibly after firefighters have departed. Further, floor joist channels are usually open to the vertical stud channels, creating an "envelope" around the interior. Thus, an interior room fire can involve exterior stud channels without visible fire extension.

The **platform frame** is built one floor at a time, so inherent firestops are provided by the floor itself. Fortunately, most modern wood frame structures are of this type. However, interconnected channels may still pose fire spread problem. Many garden apartments have interconnected voids throughout the building that

are accessible from kitchen cabinets. Frequently, only a thin board separates the top of the cabinets from these channels; a typical grease fire may spread to these channels and through the house, particularly if the cabinet is left open. Double walls used between units to cut sound offer a void for rapid fire spread. Plastic pipe for vent and drain lines--illegal in many areas--shrinks, so that surrounding plates are not tight and fire spread is possible. If you have such apartments in your area, prevention work to ensure proper fire barriers may benefit much similarly designed property.

D. Row Houses

Row houses, common in many areas, present fire spread hazards through the common cockloft. Whole blocks have been lost as firefighters try to outrace a quick-traveling fire to make a stand. Again, this is an area where **prevention** through community education and fire barrier requirements is essential.

E. Firestopping

Firestopping is an important ally in wooden buildings, though not an omnipotent one. Often, builders see small openings in fire barriers as inconsequential, unaware that size is no obstacle to a determined fire. Frequently, firestopping is removed for utilities installation, or fire barriers are pierced and rendered ineffective. Inspection is important. If you haven't seen it, assume it is not there.

F. Fire Wall

To be at all effective for wood frame structures, fire walls should extend about 3 feet <u>out</u> from the wall as well as 2 feet <u>over</u> the roof. Fire walls are sometimes built incorrectly by builders unaware of the principles involved. Also, the integrity of the wall must be preserved at all points.

G. Insulation, Sheathing, and Siding

A variety of insulation materials are used in wood frame construction. These materials are generally placed in the channels and void spaces between studs and joints. Some insulation is flammable or held in place with a flammable membrane. Other foamed insulations produce highly toxic products when heated or exposed to flame. Flammable insulation may threaten firefighter safety by fostering rapid fire spread and releasing toxic gases.

Foam polyurethane, low density fiberboard, pressed fiberboard, plywood chipboard and hardboard lap are all common types of sheathing. Foam polyurethane is toxic, and may foster fire spread within the cavity. The fire-retardant quality of fiberboard varies according to type and thickness, and plywood is vulnerable to fire. The primary fire concern is related to ability to reduce "racking" (the tendency of a building to collapse laterally or twist). As sheathing burns, the building becomes more vulnerable to racking.

Siding may contribute to safety hazards. Vinyl is associated with toxic fumes, while steel, aluminum, and asphalt may cause burn injuries. If asbestos siding is found, beware of impact wounds from hard pieces of falling siding and eye wounds caused by small flying pieces of "exploding" asbestos.

Various types of wood siding are common, including pattern wood, pattern plywood, chipboard, and hardboard lap. Tongue–in–groove siding, a type of pattern wood, is generally preferable to overlapping sidings since it provides a sealed joint, while overlapping siding may allow flame to spread through joints. Veneered cedar, a type of pattern wood, may contribute to rapid combustion.

Brick veneer is generally the greatest source of concern. In wood frame construction the brick veneer is anchored to the back-up wall by nailing corrosion–resistant corrugated metal ties to wall framing members. The ties are spaced not more than 16 inches horizontally and 24 inches vertically. It is important to inspect brick veneer buildings under construction to see that an adequate number of ties are used to connect the wall, and to analyze the potential for loosening ties according to the material of backing and ties and the overall sturdiness of the connection.

Exterior plastering may be either a stucco membrane or an admixture including plasticizers. "Stucco" is really a thin concrete slab built up by using plastering tools and methods. Like any concrete, it may spall when exposed to fire or high heat. Masonry and plastic cements are composed of portland cement, aggregate, and polymer-based admixture including plasticizers. Exposed to heat, the plasticizer will bake off and the cement base will crumble off in powder form. Spalling is possible.

H. Indicators of Collapse

A key assumption of this course is that what you know about the building may well be your only warning of collapse. However, sagging floors, bulging or leaning walls, the burning of a side wall for a long period, a large volume of fire coming through windows or breaking through the roof, are all warnings requiring immediate action. In many case studies of firefighter deaths, one finds that such warnings were simply not acted on immediately--rather, further confirmation or a second warning was anticipated. Final confirmation, remember, appears in the form of a falling building.

UNIT THREE: ORDINARY CONSTRUCTON AND ALTERATIONS

A. Key Concerns in Ordinary Construction

Ordinary construction--commonly found on "Main Steet, U.S. A."--is composed of wood-joist floors and masonry (but not veneer) walls. Materials used include brick, concrete block, or combination brick and concrete block. Ordinary construction is bearing-wall construction , so the walls are responsible for supporting the weight of the floor. Obviously, wall condition is critical to overall building stability. It's important to know which walls are bearing, since their failure means floor failure as well. Typically, the joists span the shortest distance across the building; if the distance exceeds 20 feet, an intermediate girder, columns, or a bearing wall may be added. (In modern versions of "ordinary" construction, steel is used and the old rule is no longer applicable.)

Wall thickness varies from 6 to 30 inches in older buildings. In multi-story masonry buildings, wall thickness increases at lower portions of the wall. Masonry **loadbearing** walls have two wythes minimum thickness. (A wythe is a continuous vertical section of masonry one unit in thickness.)

Loadbearing walls constructed prior to about 1950 normally can be recognized by their use of the **common bond** pattern, in which five courses of units are laid as "stretchers" with every sixth course laid as a "header," a header being a masonry unit that overlaps two or more adjacent wythes of masonry to provide a structural bond. For more recent buildings, this visual evidence is unfortunately unreliable.

In terms of fire performance, both brick and concrete block walls are poor heat conductors. This means a thick wall, in particular, is likely to function as an effective heat barrier, and may reduce the communication of fire from building to building. (Naturally, this effect is modified by the presence of windows or other penetrations.) Masonry walls tend to confine the heat of the fire within the involved structure or protect the building interior from external exposing fire.

Areas of strength include areas where reinforcement occurs (in concrete block) and, for all masonry structures, wherever walls intersect. This is because walls perpendicular to each other are mutually supporting. The corners generally tend to be the last to fall; so where a masonry structure is heavily involved it is generally advisable to make every effort to position personnel and apparatus at building corners.

When a wall does fall, debris is often projected a distance of **more** than the wall's height. The exact distance cannot be anticipated with precision because of the multiple variables involved, such as the method of failure for interior structural members. Therefore it is recommended that firefighters be positioned a **minimum** of a length equal to wall height when making a frontal attack on a heavily involved structure, and further if possible.

B. Masonry Wall Evaluation

Each of the common masonry materials has its own way of telling you if it's too tired to keep working.

Brick may **spall** as a result of frost, chemical action, or stress from the building itself. If you see flaking or fragmented brick, you can expect little help from the wall. Brick may also **crack**. Analysis of the length, depth, and location of the crack will give you an idea of its seriousness. Cracks related to potentially serious "differential" movement tend to be uniform in width from top to bottom, while generally nonproblematic cracks related to foundation movement tend to be uneven in width from top to bottom. Officers may order serious cracks marked to see if "travelling" occurs during the course of the fire.

Bricks from which mortar has **weathered** are also unreliable, since there is no longer a satisfactory bond from brick to brick. **Deteriorated** (dried out) mortar, (which may be detected; if it can be dug out with a pencil), has lost its bonding capacity. **Sand lime** mortar, which has a grainy texture, is a special problem because it is water soluble and may be removed by a fire hose, leaving you with a pile of unbonded bricks ready to topple. Portland cement, which replaced sand lime mortar, began to be available around 1880.

In modern structures a mixture of portland cement and sand lime is used that is resistant to high-pressure hose streams. It is impossible to pinpoint a single date on which use of sand lime mortar ceased, but research on buildings in your area should give you a good idea of local practice.

Efflorescence results when large amounts of soluble salts are used in the mortar and excessive water penetrates the masonry. Efflorescence appears as a white powdery substance on the wall and indicates weakened mortar.

Concrete block walls typically crack along mortar lines. Insufficient mortar will cause instability, so check on the inside as well as the outside walls. Remember that the strength of concrete is dependent, in this case, on the mortar, and the wall may have little resistance to lateral impact.

Concrete may be reinforced either vertically or horizontally. If visible reinforcing rods are found, the wall may not continue to function. A special type of reinforced concrete wall is the **shear wall**, used not in ordinary construction but in steel frame buildings to resist lateral pressure. Such a wall is an integral part of the structural support system and should not be breached.

Terra cotta walls have a proven bad record with the fire service. The blocks have little bonding surface. Further, the material is brittle and liable to crack without warning, especially given any lateral impact.

C. Alterations

In analyzing wall stability, weakness may be revealed by other signs than material quality and condition. **Disparate construction** is a source of concern since materials have different expansion/contraction rates and, in the stress of fire, may be subject to extreme stress where they meet. **Patches** are bad news for the same reason. In other cases, avoid breaching a wall near where such materials are joined.

Parging--plastering over a masonry wall with concrete--is frequently a cosmetic fix for an unattractive, deteriorated wall. A wall **out of alignment** is always a sign of danger, and should not be breached.

Spreaders are intended to spread a load among one or more structural members and are frequently used to support a wall in trouble. They are often indicated on the outside wall by a circle, star, channel, or other device. There are two basic types: one that ties the first three or four joists to the wall, and a second that ties two opposite walls together for stability, using either rods or cables (both of which fail at low fire temperatures).

It is important to note weak areas in a wall, since they are a likely starting point for failure and you do not want to hasten failure by breaching near a weak point. A **pipe chase**, either on the inside or outside of the building, is a plane of weakness. So is a **window** (or other opening cut into the wall), or an extended crack. An arch supported by a **wooden arch bar** is also a potential problem, since the arch bar is really supporting the arch (that is, it is not a true arch) and failure is likely if the bar burns away.

A key concern both for wall and floor stability is the method by which floors and walls are joined. Where joists are built directly into the wall, falling joists will act as a lever to bring down the wall. To save the walls, **fire cut** joists were designed, and cut at an angle to allow floor collapse. Firefighters should be aware of which buildings use either type of connection, since each has its special disadvantages from a safety standpoint. The safest connection--corbelling out bricks to support the joist--is found the least, since it is more expensive and time-consuming to build.

D. Indicators of Collapse in Ordinary Construction

Again, your own knowledge of the building may be your only warning prior to collapse. However, the following indicators spell immediate danger:

1.Continued or heavy fire.

2.Smoke showing through walls (may precede backdraft explosion).

3. Heavy smoke, and high heat, especially if coupled with inadequate ventilation.
    a. May precede backdraft explosion.
    b. Less reliable since plastics cause same effect.
4. Cracking noises.
5. Failure of part of wall.
6. Bowing wall.
7. Fire visible through wall.
8. Interior collapse.
9. Visible spalling.
10. Wall disassembles under hose stream.
11. Concrete spalls, rods exposed.
12. Eccentric load losing support.
13. Water between bricks.
14. Two or three floors fully involved.
15. Excessive water in building.
16. New cracks.

UNIT FOUR:
COLLECTING, FORMATTING, AND RETRIEVING INFORMATION

Fireground experience has undoubtedly taught you that it is best to know as much as you can about your buildings **before** fire strikes. It follows logically that you need an organized way of collecting and formatting reliable information and seeing that it is ready to use on the fireground. Limited personnel is no excuse. Even small fire departments can find a way to cover their area, possibly collecting even more complete information than larger departments. One small all-volunteer department, for example, was able to complete a door-to-door survey that yielded vital data on **every** building in their district. To decide what system you need or to re-evaluate your present system, the following steps should be helpful.

A. Analyze Area Characteristics

The size of your area, geographical traits, and types of structures typically encountered may all influence your information needs. It is important to consider their impact, then look ahead to anticipated changes. You certainly want to avoid designing a system that will be inadequate to keep pace with new developments.

B. Analyze Operational Needs

Your standard operating procedures may also affect your data needs, both in terms of **what** is needed and **where** it is put in the sequence of information on the page. In addition, your accident records will indicate problem areas to cover. Personnel/equipment limitations may also affect data needs in so far as they influence the way you fight a building fire. Finally, standard tactical and preventative data needs to be included on the same form and must be identified.

C. List Preliminary Data Needs

At this point, you are ready to categorize needs into **primary** and **secondary** needs. This is crucial not only for determining what must be collected first and is worth the most effort, but also for deciding what should be emphasized on the layout or printout of your reference. This list should not be considered sacred, but subject to additions, deletions, and elaboration throughout development.

D. Establish Data Resources

In a brainstorming session with as much diversity of participants as possible--community leaders, home insurance representatives, building department employees or others--compile a list of sources to check that they may provide steady information on existing and new buildings in your area.

You may already have significant in-house records, such as inspection documents, fire incident records, and preplan surveys. You will want to check local government agencies with building or property records such as the tax assessment office, the building permit office, and planning and zoning committees. Regional planning groups, the chamber of commerce, and property owners or developers may also have data. For individual buildings of special interest, or ones for which in-depth information is needed, you will

need to tap such sources as persons who have done maintenance work in the building, community residents, and newspaper clippings. From each source, collect samples for analysis.

E. Evaluate Available Data

Data may be worse than useless if it is not accurate and current. You will need to evaluate your sources' data on these points and consider the reliability of **their** sources and collection methods. At this point, sort the data acquired according to your needs list, and refine the list in light of any new ideas.

F. Establish Data Flow Channels

As you know from experience in other areas, nothing is likely to get done if no one is in charge of it. Collecting building data is no different. Someone from the fire department must be in charge of the on-going collection effort, and given adequate personnel to accomplish the task. Motivation is a key, so be sure personnel assigned to the task are aware of its importance and committed to doing it well.

Establishing the data flow will require excellent public relations skills. In some cases, an information trade may be effective. In others, favorable publicity or publicly expressed appreciation may help. The sources should be clearly aware of the service they can perform for the community. (Publicizing the benefits of the completed system may help both you and your sources.)

G. Determine Data Format/Storage/ Retrieval System

The appropriate system for your department must, as we have been saying all along, evolve from your specific needs. The **format** in which the information appears should highlight top priority needs, whether by spacing, size, or indications such as circling, underlining, color-coding or symbols. The end use of collected material should be kept firmly in mind; a bulky system will not be consulted frequently. Consider making the text as brief and concise as possible and reinforcing it by clear drawings. Separate different types of material in an appropriate way so that what is needed for a given purpose can be found without time-consuming searches through irrelevant material.

The **storage system** may range from a stack of index cards to a computer-equipped command unit. In selecting a system, consider the pros and cons relative to your particular situation with care. A **computer** has the advantage of large capacity, storing highly detailed information compactly. Information may be easily and economically updated. However, there is an initially high equipment cost, and field use requires additional expense. The system is not easily portable.

Microfiche provides the advantage of very compact records and detailed storage of existing drawing and photos. However, it is not easily updated and the card reading equipment is bulky for field use.

Looseleaf binders can easily incorporate photos and drawings, and are easily updated and portable for field use. Further, multiple copies can be easily produced. However, their durability is limited and large files may become extremely bulky. While **card files** are compact and easily updated, they offer limited convenient storage capacity.

Some appropriate ordering system must be devised to retrieve information, whether by use of coded sections on a city grid, occupancy type, or street address. Retrieval aids such as a contents page, an easily updated page numbering system, color-coding, or retrieval by computer may also be explored.

Retrieval location options include the dispatch center, fire station, fire apparatus, or a special vehicle such as a mobile command unit. Note that **accessibility** is the key. Whatever form is chosen must be durable, weather-protected, and as protected as possibile from separation and loss.

Finally, the **retrieval system** chosen must be appropriate for your department. If the information you need is in a command car that may not arrive, your system is not well chosen. Even if available, it may not be used unless personnel are trained in its use and motivated, so that use of it is automatic.

H. Field Test and Evaluate

There is no point pretending your system is perfect from day one. Rather, why not allow all the users of the system to offer suggestions on perfecting it? By listening to them and making appropriate changes, you will end up with a usable, and used, retrieval system that can make a priceless contribution to both efficiency and safety.

SUPPLEMENTARY READING
NONCOMBUSTIBLE AND FIRE-RESISTIVE CONSTRUCTION

INTRODUCTION

A. Historical Perspective on Fire Resistance

Because fire-resistant construction procedures have varied through time, it is important to be conscious of building history. Even if you do not have many older buildings in your area, great and no-so-great ideas from the past have a way of resurfacing with modern twists, and historical perspective may prevent tragic recurrences.

For early fire-resistant buildings (roughly 1870-1930), procedures were based on "guesstimates": nobody knew much about how materials would perform in actual fires, and many theories had to be proven false by experience. Cast iron columns were left unprotected, though their fire performance turned out to vary drastically based on workmanship. Cast iron building fronts could collapse separately from the building, a scenario even more likely in modern times as ties degenerate.

Floors of these early buildings were composed of brick or tile segmental arches tied by steel, which could fail as the exposed steel began to relax. Cutting through such arches for ventilation proved dangerous because of the interdependence of the arch as a structural form. (This also applies to terra cotta tile.)

The danger of wide-open stairways as channels for fire spread was initially unrecognized. In the famous Parker Building fire in New York City, a 20-story building was destroyed by fire spread up open stairways, spurring development of ASTM E119.

Today, firefighters entering such structures must often cope with alterations that have radically altered the building's support structures. For example, bearing walls may have been removed and replaced with steel column/beam systems. The presence of unprotected steel will increase the collapse potential of the building. Combustible voids often exaggerate the problem.

Fire-resistive buildings constructed between the world wars (1920-1940), however, are considered by many to be the most fire-resistant structures we are likely to see. Construction was massive, floor areas limited, and space between windows generally sufficient to restrict exterior fire spread. High-rise buildings were universally steel frame heavily encased in concrete, and floors were of concrete or tile. Solid compartmentation was provided both within and between floors.

With modern structures, fire resistance in some respects moved backward. Since the mass of a structure bears a direct relationship to its fire resistance, the push to reduce mass and use lightweight construction often leads to a dangerous combination of fire service overconfidence (based on older structures) and reduced working time. The general trend is called "optimization," since it seeks to get the most out of each bit of structural material. The truss (including the common bar joist) and the space frame (a three-way truss often

used as an exposed roof support) are examples of optimization. A structural form in which all members are interdependent, the lightweight truss may fail early in a fire with no perceptible warning. Examples of truss roof collapses covering large areas are, unfortunately, accumulating. The C. W. Post Auditorium (1978), the Hartford Coliseum (1978), and the Kemper Auditorium in Kansas City, Missouri (1979) are all examples of truss roof collapses in which human life loss was minimal primarily due to luck.

In addition, the advent of air conditioning and fluorescent lighting has led to broader and broader occupied areas, often only partially compartmentalized by flimsy materials. Combustible and toxic insultaion added new problems, as well as an increased use of plastics. Greater requirements for electrical service and communications increased the amount of void space in the building. These services often breach potential fire and smoke barriers, posing fire spread problems.

Exterior extension, too, is often more likely. Flat curtain walls are often inadequately firestopped, creating a potential "chimney" along the building side. The distance between windows has decreased, and masonry "belts" separating floors are less common. In the Playboy building fire in Los Angeles County, California, for example, fire spread from the third floor to the seventh by means of outside windows.

While building codes have struggled to regulate the infinite variety of building practices, research often lags behind usage, and political expedience seldom supports those concerned with fire safety. It is important to try to spot "loopholes" in your own code, for they are surely there. Even in fire-resistive construction--a very different animal from noncombustible construction--fire-vulnerable elements may be introduced: steel unprotected above a certain point (but near a tall dry Christmas tree), a top floor of noncombustible or even combustible construction, a column not fireproofed in the plenum space because it is "protected by the ceiling" (which happens to have a tile missing).

Know your code, and know its limits. Then apply what you know about human nature. The estimate you make in your size-up will need to have all these factors clearly in mind.

B. Key Terms

A **noncombustible material** is currently defined in NFPA Standard 220, **Building Construction,** as "a material which, **in the form in which it is used and under the conditions anticipated**, will not ignite, burn, support combustion, or release flammable vapors, when subjected to fire and heat." The qualifying statement underlined is extremely important, and makes the fire officer's job much more difficult. Materials are tested--when they are tested, and most are not--under particular test conditions, carefully controlled so that the performance of one material may be compared with that of another. In the real world, of course, the material will be in a more complicated environment with many untested variables.

Not only is there no guarantee that such a material will never support combustion, but there is no mention of dangers that may result from other fire reactions of the material: for example, steel's tendency to elongate and relax may precipitate a collapse under the right circumstances, and it is not much help to recall that the material did not actually ignite. In short, it is critical to recall that noncombustible does not mean "safe." And it certainly does not mean "fireproof"--as 19th-century builders discovered to their sorrow, after many disastrous fires in buildings believed to be fireproof simply because their elements were noncombustible.

The concept of fire-resistance goes beyond that of noncombustibility. It refers to the "capacity of a material or construction to withstand fire or give protection from it; characterized by its ability to confine a fire and/or to continue to perform a structural function." A standard test for fire resistance is conducted by placing the assembly in a test furnace. Floor and roof specimens are exposed to fire from beneath; beams, from the bottom and sides; walls, from one side; and columns, from outside. The temperatures in the furnace increase at prescribed intervals: 1,000° F at 5 minutes, 1,300° F at 10 minutes, 1,700° F at 1 hour, 2,000° F at 4 hours.

These time-temperature relationships are based on a curve adopted in 1918 and introduced in the 1918 edition of ASTM Methods of Tests of Materials and Construction. Recently, however, important research by the Center for Fire Research at the National Bureau of Standards suggests that the time-temperature curve is in need of revision. The center conducted 16 full-scale fire tests in a typically furnished basement recreation room with prescribed variations in room size, fire load, densities, interior finish materials, and ventilation conditions. To quote their study: "The rate of development and the intensity of real fires involving the burning of typical furniture and interior linings in a room may be significantly greater than those defined by the ASTM E119 standard time-temperature curve." In other words, as a result of contemporary materials and furnishings, modern fires may be faster and hotter than those that provided the model for the ASTM curve.

The performance of a given assembly under actual fire conditions may be quite different from that in the test, so the fire officer must be alert to variations in the particular environment where the assembly is used. It helps to know as well what the assembly has actually been tested for, which is different depending on the building element. Floors and roofs, we find, are tested for their ability to sustain a load and their resistance to flame passage or heat transfer to the side not exposed to fire. Walls pass the same test, and must also sustain a hose stream test. Beams and columns need only demonstrate continued ability to sustain a load. In addition, members that contain steel are checked to see that steel temperature limits for a given time limit are not exceeded.

The test is terminated and a fire resistance rating is assigned when

the member fails at any of the tasks it is being tested for: when it fails to sustain a load and collapses, allows flame passage or heat transfer, disintegrates under the hose stream, or exceeds temperature limits for steel. The rating thus attained should be considered a best performance, and in no way a guarantee that the tested item will hold up for precisely two hours, say, no matter what. A missing ceiling tile, a heavy fire load, or poor maintenance, to name only a few possibilities, may radically alter fire performance.

Consider, too, what fire-resistance ratings do **not** reflect: containment of smoke and toxic products, life safety, and dollar loss. The fact that the walls are still standing is of little help if scores of people are killed by toxic products trapped within these walls. It is important, therefore, to keep in mind the **total** design of the structure and the dangers posed by its specific features.

C. Murphy's View of Fire Resistance

Remember Murphy's Law: "What can go wrong, will go wrong!" Murphy would be a good firefighter. Approach noncombustible and fire-resistant structures with a healthy suspicious attitude. Maybe the materials used are not up to the quality sent by the manufacturer for testing. Maybe the architect came up with an "equivalent" design that was never really tested, and may turn out to be not equivalent at all. Maybe the contractor will substitute materials already in stock, or that he got a better deal on. Maybe the workman is a bit tired that day and is not paying much attention, or maybe he is disgusted with complicated special instructions and does the work in a faster, simpler--and less fire-resistant--way. Remember, fire is not first in the minds of key individuals during any of these crucial steps in the long path from testing to installation and use. Their primary concerns are generally getting the article in question to stay up and, if it is visible, to look good.

The occupant is likely to be even less conscious of fire, and therefore less likely to perceive a ceiling, for example, as a fire barrier. It's just a ceiling. It may be a convenient place to store old magazines when space runs out. A ceiling in a little-used area, such as a storeroom, is not likely to be very high on the list for repairs. Workers who come in to repair (II-8) plumbing and HVAC systems are also not thinking of fire; they are thinking about getting to whatever needs to be repaired as quickly as possible, fixing it, and getting out.

So it is important for the fire suppression officer to remain vigilant during construction and keep open lines of communication with fire inspection personnel. Familiarity with the building practices of a given contractor or other pertinent data may be extremely useful, even critical, to safe and effective fire command.

Bear in mind, too, that the impact of Murphy's Law may be reduced by ongoing communication with allied professionals in your community. If you build a reputation for credibility and consistency in your area of expertise and respect **their** expertise, a relationship may develop that can be a real advantage to both. You will find reliable sources of information on new building methods and materials, and they will find an articulate representative for fire department concerns.

UNIT ONE: STEEL AS A STRUCTURAL MATERIAL

A. Characteristics of Steel

Steel is highly favored by building designers in spite of its cost, since its high strength and factory-controlled quality often make it cost-efficient. It occurs in a variety of different types which have different characteristics, and while you cannot always know exactly what kind of steel you are dealing with, it is very important to recognize the variability in fire performance and make a reasonable guess as to what you have.

The characteristics of steel are modified by its composition. Carbon content increases "brittleness" and decreases ductility, so a high carbon product such as cast iron is much more likely to break or fracture without deforming than the lower-carbon structural steel. Alloys may be added to produce special characteristics, such as resistance to rust.

Mechanical working may also affect the characteristics of steel. Of particular importance to the fire officer is cold-drawn steel, used for elevator cables, prestressed concrete tendons, and other situations calling for especially high strength under tension. Cold-working decreases ductility, so failure without warning is to be expected. Also, cold-worked steel of any variety tends to fail at much lower temperatures.

Structural members are likely to contain either structural steel (also called "carbon" steel), which has a strength range from 33,000 to 45,000 psi (pounds per square inch). A special type of high-strength, low-alloy steel, a lighter steel often used for high-rise construction, has a higher strength range: 42,000 to 75,000 psi. Specially heat-treated steel may achieve a strength range of 70,000 to 125,000 psi, while cold-drawn steel may be used for stresses as high as 150,000 psi. Either of the last two types may be found in prestressed concrete.

B. Fire Concerns

Steel loses strength as temperature increases. Cold-drawn steel and high strength alloys begin to lose strength at lower temperatures than structural steel, so fire performance is highly dependent on the effectiveness of whatever barrier is supposed to insulate it from fire. All building elements are designed with a "factor of safety" in mind, but high fire temperatures may drop steel strength levels below that factor of safety much faster than you think.

Steel also softens as it heats. This can cause a thin element, such as a slender column, to buckle suddenly without warning.

Further, steel elongates at high temperatures. At 1,000° F, length will increase approximately 1 inch for each 10 feet. At 1,300° F, the increase is about 1% of total length: a 50-foot beam is trying to expand 6 inches. If that beam were completely restrained (unable to move), it would encounter an induced compressive force of 250,000 psi--well beyond the strength range of any type of steel. Depending on how the steel is used, severe stability problems may result.

The tendency of steel to conduct heat may also cause problems, such as the transmission of heat from floor to floor by way of steel expansion joints, or the extension of a grease duct fire to adjacent construction.

C. Key Factors in Fire Performance of Steel

The key factors in steel fire performance may be summarized as follows:

1. **Type of steel.**

As noted above, some types of steel lose strength more rapidly than others under fire conditions, so it is dangerous to generalize too readily from one fire experience with steel to another.

2. **Loading conditions.**

Occupancy changes or environmental loads such as high winds may subject the building to undesigned loads (loads the building designer did not anticipate) which will contribute to early failure.

3. **Temperature.**

The temperature reached by the steel is largely a function of mass and shape. The more exposed surface a member has in proportion to its mass, the more quickly it will heat. This critical principle, mathematically expressed as the "surface-to-mass ratio," can hardly be overestimated as a determinant of fire performance.

In some fire situations, part of a steel member may be much hotter than another. The critical temperature for failure is generally considered to be 1,000° F average temperature of the cross section, or 1,200° F at any one location. (Bear in mind, however, that loading conditions may cause the member to fail even earlier.)

4. **Fire severity.**

It must also be recalled that an intense fire may not have been planned for when building components were tested and installed. Building contents are largely unregulated except by occupancy, but fire loads vary greatly within an occupancy--from lobby to storeroom, for example.

5. **Connections.**

The type of connections used has implications for fire failure. The more rigidly members are connected, the more they will be able to support each other when a member weakens. On the other hand,when a rigidly connected member does fail, connection may be strong enough to pull other members with it, while a more loosely connected member will no necessarily bring others along (at least not immediately).

6. Materials combination.

The degree to which materials used with steel may complicate fire performance is frequently not appreciated. In most metal deck roof assemblies, for example, the adhesive used to connect insulation to the metal deck releases a hot gas that will start a fast-rolling, self-sustaining fire as the hot adhesive drips through metal seams. (Dripping tar is a frequent clue to suspect a metal deck roof.)

D. Steel Framing

Steel framing is either typical skeleton frame or long-span framing. A skeleton frame uses beams and columns to support building loads, as opposed to the masonry bearing walls that support loads in ordinary construction. Often steel frames are built in bays of identical dimension and structure, a feature that allows cost-efficient construction for appropriate structures.

Where long spans must be covered without visible supports, a number of options exist. The builder may use stronger "built-up" girders, or may elect to use constructed assemblies, such as the various forms of "truss" construction. Arches, cantilever-suspension spans, and rigid frame structures may also be used.

While rigid frames tend to hold up longer under stress since members are so tightly connected that they may lend support to a broken or failing member, the tight connections mean that when part of the structure does give way, much of the surrounding area may go with it. In other words, the collapse zone will be larger. Rigid frame bents (placed crosswise to support lateral as well as vertical loads) are often tied under the floor, so if the ties are exposed to fire from beneath they may fail and cause the collapse of the structure. In addition, note that the use of rigid connections allows increased strength with smaller members ("optimization") so this is a situation in which fire resistance is not inherent.

E. Connection for Steel Members

There are four basic types of connections for steel members. **Welding** is a process by which liquid metal is fused with parts to be joined. Improper welds are subject to fracture in cold weather, and all depend for strength on the skill and training of the welder. **Riveting**, common before the 1950's, involves pressing hot rivets into holes in steel. **Ordinary bolting** requires tightening bolts with a spanner until they feel tight, which has an obvious element of subjectivity. **High-strength bolting** is generally more reliable, since it requires the use of a torsion wrench that can be precisely calibrated.

F. Fire Protection Methods

There are three common fire protection methods: encasement, spray, and membrane.

Encasement requires that steel be surrounded by material that can protect it from fire, such as metal lath and plaster or concrete. Such

protection is dependent on the complete integrity and thickness of the encasement for effectiveness, and, if flat boards are used, on the fire resistance of the connections joining them.

Spray protection may consist of cementitious mixtures (mixed at the job site), mastic coatings (premixed), or fiber spray. For all spray protection, completeness and prescribed thickness are important to effectiveness. A danger for most types of spray protection is that they may be scraped off for the installation or repair of building services, such as HVAC. A hose stream can also dislodge spray protection.

Membrane protection relies on a suspended ceiling to protect steel members in a floor/ceiling assembly. The entire assembly and any utilities that penetrate it are tested together and rated as one. Any changes from the tested assembly will cause fire performance to deteriorate: the omission or removal of required "hold-down clips," for example, may make it easy for thermal drafts to lift the ceiling tiles and penetrate the planned fire barrier. Also, tiles are often removed for repairs, and may remain missing for months. Because of the complexity of this method, it is highly subject to impaired performance.

Other less widely used approaches to the fire protection of steel include the use of **water-cooled columns** in which heat is controlled by convection currents, **flame shields** that deflect flames from exterior spandrel beams, and **separation**, in which exterior columns are moved from window openings to control excessive heat.

UNIT TWO: CONCRETE AS A STRUCTURAL MATERIAL

A. Concrete Composition and Production

Unlike steel, which is produced under controlled factory conditions with reasonably consistent results, concrete's strength is dependent on the skill of local workers in mixing it, pouring it, controlling its temperature during curing, and allotting sufficient time for it to reach full strength. At every step, quality control is essential.

Concrete is a mixture of portland cement (a binding agent), water, and an aggregate. The strength, amount, and attributes of the aggregate chosen will be important in determining the characteristics of the concrete. The **ratio** of these ingredients is obviously critical, and changes may have drastic results. In general, the higher the water/cement ratio, the weaker the cement.

During the **curing** process, concrete hardens and obtains full strength through a chemical reaction called hydration. Proper curing depends on an appropriate ratio of ingredients and moderate temperature. Improper curing may result in cracking that can seriously impair quality. Proper placement of the concrete is also critical. Errors may result in air pockets, separation of aggregate, or other problems. A pattern known as "honeycombing" often is a sign of improper placement.

B. Concrete Types and Fire Behavior

Concrete is classified according to weight. Normal weight concrete is used for structural elements. It has good compressive strength (about 4,000 psi) but steel is at least 10 times stronger. Further, it has little or no tensile or shear strength, and is dependent on steel reinforcement when such strength is required (as for a beam). Though it is seldom critical to fire performance, ordinary reinforced concrete has a tendency to "creep," or deform over time, as a sustained load squeezes water from the pores of the material. This tendency causes cracking, which occurs in proportion to the heaviness of the load. If new concrete were asked to support an unexpectedly heavy load, the cracking might be severe enough to seriously expose the steel reinforcement. Such exposure would mean that the concrete is no longer functioning as a composite material and might fail.

Unlike steel, concrete is a heat sink, which means that it tends to contain heat rather than conduct it elsewhere. The result of this quality is that the building is likely to become an oven, so that frequent relief of firefighters is a necessity. Overhaul may need to be delayed until the building has cooled somewhat.

Concrete reacts to heat by cracking, crazing, and spalling. Since spalling is a result of the expansion of the moisture in the concrete when exposed to heat, new concrete is most apt to spall because of its relatively high moisture content. The application of a hose stream to hot concrete may result in crazing or spalling. Spalling may occur as a gradual erosion, or may be explosive. In either case, it reduces time to the failure of an element. Because of the danger of spalling,

eye protection must be considered. Because of the expansion of moisture in concrete when heated, old-fashioned "Lally columns"--steel piles filled with concrete to increase load-carrying ability (and their modern equivalents) are liable to explode in the event of fire, especially if no vent for steam is provided (as is often the case). Spalling can also result from materials embedded in concrete that cause chemical reactions. An example of this is the electrolytic action resulting from dissimilar metals, such as aluminum conduits used with reinforcing bars.

Structural lightweight concrete is of medium density (85-115 pounds per cubic foot) and is used for non-structural panels, roofs, and low-rise structural members. It tends to spall less, maintains strength longer than regular concrete, and is a better insulation.

Insulating lightweight concrete of low density (30 pounds per cubic foot) is used primarily as sprayed fireproofing for steel and insulating fill on steel corrugated decks.

Property variations are obtained through admixtures. Examples include expansive concrete, which minimizes cracking due to shrinking; early strength concrete; and air-entrained concrete, which contains small air bubbles to improve workability and weathering.

C. Concrete Classification by Casting Site

Concrete may also be classified by casting site, a consideration which has definite implications for fire stability. **Cast-in-place** concrete has the advantage of naturally rigid joints, which increase resistance to hurricanes, explosions, or earthquakes. **Precast** concrete, however, is often dependent on unprotected steel connectors for joints. Special types of precast construction present their own specific problems. Tilt-up construction, for example, relies on the roof to stabilize the walls; **lift-slab** construction is particularly vulnerable to collapse when under construction: and **panel construction** is apt to contain unprotected joints. Precast (or other) curtain walls attached to high-rise structures pose two major problems in the event of inadequate protection: the loosening of panels from the building, and the creation of a vertical void between the wall and building that may spread fires between floors---as was the case in the 1 New York Plaza fire, to name one famous example.

D. Classification of Concrete by Reinforcement

Without reinforcement, concrete can be used only for nonstructural wall panels or foundations. With reinforcement, its ability to assume any shape gives it an almost limitless range of structural uses. Reinforced concrete may be either **reinforced conventional** or **prestressed**. Conventional reinforced concrete uses regular structural steel. Prestressed concrete, however, makes use of high-strength steel that is subject to failure at much lower temperatures, and may lose fully half its strength at temperatures as low as 800° F. Further, because of the tremendous pressures locked into members, a break in the tendon may cause it to strike objects or persons with devastating force. Obviously, adequate concrete cover is even more a key consideration than for regular reinforcement, yet there may be little more than an inch of concrete between tendons and the outside edge of concrete.

Prestressed concrete is classified according to whether tension is applied before or after the concrete has cured: pretensioned or post-tensioned. Post-tensioned prestressed concrete is of particular concern when under construction, since it may be in place but not yet up to strength because tensioning is not complete. Also, the ends may not be protected, exposing the steel to high temperatures. In any case, failure of a tension cable should be assumed to cause immediate member failure.

Key variables in the fire resistance of concrete may be listed as follows:

1. Type of concrete

Concrete has different degrees of fire resistance depending on how it is formulated.

2. Loading conditions

Especially important when new.

3. Type of reinforcement

Prestressed tendons fail earlier, and pose particular hazards when stress is released.

4. Amount of concrete

Mass increases fire resistance. The amount of concrete protecting reinforcement is critical.

5. Integrity

A fire-resistive concrete barrier is of little use if penetrated by poke-throughs.

6. Presence of combustible elements

A fire-resistant building may have many vulnerable elements, including the roof and ceiling.

7. Presence of voids

The way the void space in the building is used may impair fire resistance by adding fuel load.

8. Connections

Where concrete must rely on connections, time to failure may be only the time to connection failure, which may occur long before the concrete itself deteriorates noticeably.

9. Alterations

As a building ages, combustible or fire-vulnerable elements such as unprotected steel are increasingly likely to be present.

10. Condition

The condition of the concrete (excessive cracking, or exposed reinforcing rods) will also affect fire performance.

UNIT THREE: THE PRINCIPLES OF FIRE GROWTH IN BUILDINGS

A. Fire Growth Analysis in Modern Buildings

Each fire is complex and different from every other because of the hundreds of variables that operate in any given environment. However, there are points of comparison that are relevant to every fire, and which will assist us in analyzing what might or did occur in a given fire. It is helpful to consider the fire growth process in five basic stages and discuss the key variables that have the greatest impact on any given stage. These stages are ignition initiation, initial item development, intra-spatial development, intra-compartment development, and inter-compartment development.

1. Ignition initiation

In this stage, the fire moves from a preheat stage to flowing, then flaming combustion. This may happen rapidly or very slowly; in fact, the "fire" may smoulder for hours, releasing toxic products.

Whether ignition occurs is dependent on the energy of the ignition source and the properties of the fuel. A high energy source may succeed in igniting an otherwise unpromising fuel, or a highly ignitable fuel may respond to a low energy source. The ignitability of the fuel--the ease with which it can be set on fire--is dependent on the ignition temperature, thermal inertia, and surface texture of the material.

The **ignition temperature** (the temperature at which a material will continue in the process of combustion without an external source of energy) must be seen in conjunction with the **time** factor. Wood will ignite at about 600° F after 6 seconds exposure, but may ignite at temperatures as low as 212° F if exposed for longer periods. **Thermal inertia** refers to the tendency of heat to collect on the surface of the material, while **surface texture** encompasses both the shape of the material and the surface area per unit volume. Corners and sharp edges are relatively easy to ignite (which is why the corners of heavy timber beams and column are chambered). In general, the amount of exposed surface enhances ease of ignition.

2. Initial item development

As flames spread over the initial item, a key question is **orientation:** Where is it in relation to other items in the room? For fire to spread, its energy must be directed to other surfaces with sufficient time and energy to get them to their ignition temperatures. The higher the rate of energy release as the item burns, of course, the greater will be the temperature, and thus the likelihood of ignition.

3. Intra-spatial development

As fire spreads across the space of the room, the growth rate tends to increase. In analyzing development at this stage, it is helpful to

view the space in terms of "fuel packages." A "fuel package" consists of materials close enough to spread fire in either of two ways: continuity of surface (actually touching) or continuity of thermal radiation (close enough to ignite through radiant heat).

If the walls and ceiling of the fire room reach the same temperature as the fire, the temperature will soar and "in a flash" flames will completely involve all flammable material. This, of course, is flashover. It was once thought that fire load was a key determinant of flashover potential, but the distribution of fuel is now considered equally significant.

For flashover to occur, there must be a high rate of energy release. Temperatures will be higher if the fuel is located where radiant heat will be reflected back to it, as in a corridor or a corner, for example. The potential for fire severity or flashover is then greater in such locations than if the fire were located in the center of a room. In a corridor, a "fuse train" effect is created as radiant heat is reflected back from the sides to fuel fire growth. Low ceilings will also increase temperature, while higher ones allow heat to dissipate before reaching the ceiling.

In addition to fire, load and fuel volume, ventilation and the thermal inertia of barriers are key factors in determining the potential for flashover or fire severity. Walls that have high thermal inertia are mixed blessings. Highly insulated walls and ceilings will absorb heat, increasing the severity of the fire in the area they enclose; however, they may prevent its spread to another area.

In terms of ventilation, consider the distinction between an air-rich and an air-lean mixture.

An **air-lean** mixture is a fire in which there is enough oxygen to support combustion, but not enough to burn all the fuel rising with the fire gases. The burning rate of this type of fire is controlled by the rate at which it can get air. Characteristics include long flames (the unburned fuel begins to burn as soon as it reaches oxygen), black sooty smoke (usually), and smoke moving ahead of flame (often rising in a large column).

An **air-rich** mixture is a fire in which there is enough oxygen to support combustion and burn fuel. The burning rate of this fire will be controlled by the fuel surface area, the type of material burning, and the special characteristics of the material. Often the fire will burn at or right above the surface, so there is comparatively less smoke. Most severe fires occur when there is enough oxygen to keep the fire going, but not enough to make it air-rich.

4. Intra-compartment development

If a fire is air lean, but not air starved, spread is likely. The fire will use any available openings in search of oxygen. In an air-rich mixture, on the other hand, fire tends to burn at or right above the surface. Most life loss tragedies occur in situations in which the fire is not starved, but not air-rich. The rate of fuel release is so high that the fire cannot find the air it needs to burn in its own space, so smoke is pumped around the building as the fire spreads in search

of oxygen. Available openings are also an obvious factor in intra-compartment development.

5. **Inter-compartment development**

In conceptualizing fire growth, it is helpful to clearly distinguish compartments--areas bounded by solid partitions where fire may be confined--from rooms, where barriers are broken by penetrations. The fire will certainly make this distinction. In general, barriers fail from one of three causes: incompleteness, poor thermal resistance, and structural collapse.

A few final words are necessary about the importance of clearly distinguishing **rate of burning** estimation from that of fire growth potential generally. In many situations, the rate at which a material burns is much more important than the total amount of fuel available to be consumed. In a closed environment such as a public transportation vehicle, especially in a subway environment, rapid safe exit is essential. A firefighter asked to comment on materials selection would be well advised to focus on **rate** of burning. Rate of burning is determined by the **availability** of fuel and air, and the **temperature** of fuel and air. Prediction of burning rate must include an estimation of material ignitability, fuel load, and key environmental factors.

Economic, social, or aesthetic considerations frequently cause changes in building practices that have an impact on fire growth. A firefighter must be prepared to apply the basic principles of fire growth analysis to new situations, rather than risk making outdated and misleading assumptions about buildings.

One example of a trend that has dramatically affected fire growth in modern buildings is **open planning**, a means of providing more flexible interior space by removing walls as fixed elements and replacing them with easily removable partitions. In a building so arranged, there are likely to be few inherent barriers to fire spread, and those that exist will primarily make the work of getting to the fire more difficult. Since partitions are seen as furniture, not structural components of the building, they will probably not be code regulated. They may be highly flammable, and generate a great deal of smoke and toxic products. Also, the tendency to base electrical components in these partitions poses both an ignition and electrocution hazard since panels that contain metallic components may become electrified.

Energy-conservative technology also poses significant fire growth hazards. Often ignition hazards are posed by insufficient space between heat-generating and concentrating equipment and adjacent materials. The need to get heat easily from the source to remote areas tends to break down compartmentation, while low ceilings intended to concentrate heat in occupied areas allow rapid horizontal fire spread and the possibility of fire impingement on overhead structural components. **Thermal masses** used to reradiate heat may increase fire intensity by raising temperatures. In addition, the "tight" quality of these structures may mean toxic gases

are confined, endangering occupants. Some have taken the notion of the concealed space to the extreme, designing "envelope structures" with spaces entirely surrounding the building in order to evenly distribute solar heat. Such use of space stresses yet again the need to keep a questioning mind about the surfaces above us, and to thoroughly investigate our suspicions as to what they may be hiding.

B. Interior Finish and Contents

No matter how fire resistant and well planned a building may be on paper, the occupants bring in contents that may change the picture considerably. Interior finish materials can and have contributed to damage and life loss. Basically, materials influence fire development by fostering its ability to begin, develop, and spread and by influencing its intensity and duration.

Interior finish materials may affect a fire by increasing fire extension by surface flame spread, or by contributing to the speed with which flashover occurs. Also, they add fuel to the fire, and generate smoke and toxic products. To estimate the problems to be expected from a given material, it helps to know the nature and limitations of test data on the material that may be available.

The "tunnel test" (ASTM E-84) is used by most codes to regulate **ceiling** and **wall** surfaces. The test requires a sample about 30 inches wide and 24 feet long to be placed on the ceiling of a tunnel for testing. It is ignited at one end, and every 30 seconds the following information is recorded: the distance flame has traveled along the tunnels, the temperature, and the density of products of combustion. The data are then used to assign a **flame spread** rating, based solely on the time required to reach the end of the tunnel and sometimes a **hazard** rating that comprises flame spread, fuel contribution, and smoke density. Notice what this rating does **not** include--use of material anywhere other than the ceiling, flame passage, ability to remain in place, or effect of use in combination with particular adhesives and other materials, to name only a few of the key considerations omitted from test data.

Other materials tests include the Radiant Panel Flame Spread Test (ASTM E-162), which uses samples as small as 6 inches by 18 inches and may be useful in post-fire analysis; and the "pill test," which measures whether the material is easily ignitable by a small source such as a dropped cigarette.

An especially difficult area is toxicity testing. Most researchers believe there is no current test that can confidently be used to control the use of materials on the basis of toxicity, since toxicity levels depend on the **conditions** under which the materials burn, increasing as availability of oxygen decreases. A "toxic hazard" is therefore defined as an interaction between the material and its environment.

A fair analysis of toxic hazard would have to include the following **key factors:** quantity of material present, configuration, proximity of other combustibles, volume of compartments to which combustion may spread, ventilation conditions, ignition and combustion properties of material(s) present, presence of ignition sources, presence of fire protection systems, and building occupancy.

The fire officer will need to keep **all** these factors in mind to make informed recommendations relating to life safety in his or her area, as no code is likely to be devised that can ever take all these variables in account thoroughly enough to prescribe a safe standard for every possible situation. These variables will also need to be taken into account in preplanning for safe removal of occupants in the event of fire. The material presented in the next unit will aid in determining where such products may be carried in the event of fire so that the safety of exit routes may be assessed.

Your best asset in acquiring information on finishes used in your areas is an inquiring and skeptical mind. You may wish to collect labels from construction sites and check them against the Underwriters Laboratory Directory, or a similar source. You may also consult architects, building engineers, consumer advocate groups, manufacturers, and fire protection engineers. When you are told a substance is "fire-tested" and therefore safe, you will want to ask, "by whom, and for what, was it tested?" Note that when you conduct walk-throughs of buildings for information purposes,you should refrain from issuing orders for materials to be removed or work altered that could result in a lawsuit. Report the possible problem to the individual who has legal jurisdiction in the area concerned.

Some warning signs suggest possible problems, such as very thick carpets, textured wall items, high gloss finish on wood, very thin paneling, unusual shapes probably created by plastics, or a thin peelable surface on imitation wood paneling that suggests use of a photographic process associated with toxic products. On the fireground, you will be alerted by rapid flame spread, irritating odors, heavy volume of fire, unusually dense or colored smoke, or the inability to extinguish the fire with means you would expect to be adequate.

Problems with interior finish often result not from the fire properties of the product itself, but from the way it is used or installed. For example, carpeting may be tested for floor use but applied to walls, where its position will increase flame spread. Flammable fabric may be used in special situations or for special effects. Decorations may be added to ceilings or insulation may be laid in too close to light fixtures. It is important to be alert to unusual variations from standard installation practice that may spell trouble in the event of fire.

UNIT FOUR: THE PRINCIPLES OF SMOKE SPREAD IN BUILDINGS

A. Analysis of Smoke Movement

Smoke is defined by the American Society for Testing of Materials as "the airborne solid and liquid particulates and gases evolved when a material undergoes pyrolysis or combustion." Smoke can occur **without** combustion, during pyrolysis, as substances are chemically decomposed by heat. It can spread further and often faster than flames, by rules different from those governing fire growth.

Its consequences, both in life loss and property damage, are often greater than those of fire; in fact, it is the cause of death in **at least** 80% of fire-related deaths. It contributes to panic and obscures vision, impeding both occupant escape and firefighting operations. In addition, it carries toxic products that can harm or kill when either **concentration** or **exposure time** exceeds allowable levels. Because its potential impact is so great, the problem of smoke movement is worth careful separate analysis in pre-fire planning. This requires looking at the influence of each of the five major driving forces of smoke movement and preparing to handle "worst case" scenarios that reflect their possible interaction.

1.Buoyancy

Buoyancy refers to the tendency of heated smoke to rise due to its reduced density. It causes smoke to rise to the floor above the fire floor through leakage paths in the ceiling, and to move through any leakage paths in the walls or around the doors of the fire compartment. Its effect usually decreases with distance from the fire, as the temperature drops. This may cause smoke to "stall" if no other forces are introduced to drive it further.

2.Expansion

As smoke heats, it expands in proportion to its absolute temperature (measured in degrees Kelvin) and seeks to occupy a greater volume. Where this tendency to expand is restricted, however, **pressure** will increase, driving the smoke to make use of every available pinhole. If oxygen is suddenly introduced into such a sealed environment, an explosion is possible. Like buoyancy, expansion is mainly important in initial movement of smoke from fire. As distance increases, other factors become more significant and building air currents will take over.

3.Wind

Wind may be a significant driving force, and may have a profound effect on ventilation--for good or ill. Its principal effect is to cause the smoke to move toward the leeward side of the building and toward side walls. During hurricane-force winds in 1960, glass panels were blown in on the windward side of a high-rise structure and sucked out on the leeward side. Because they are falling from such height, the danger of windows being broken or blown out is a

considerable concern in the event of fire: windows have sliced through car roofs and hose supply lines. Further, a broken window on the windward side will drive both fire and smoke back into the building. A broken window on the leeward side of the fire compartment, however, may assist in alleviating smoke conditions.

Three factors are important in determining the potential impact of wind:

a. **Building height.** The taller the building, the greater the wind influence.

b. **Wind velocity.** The greater the wind speed, the greater the impact.

c. **"Leakiness" versus tightness.** The "leakier" the building--the more doors and windows are open, and the more poorly sealed the compartments--the greater the impact of wind.

It is also important to recall that wind direction and velocity may vary from higher to lower floors in high-rise structures, and may shift suddenly. False assumptions may cause great problems, so it is important to check before acting on them. Finally, bear in mind that building shape may modify wind effect, as the air will always take its easiest route: in a short, wide building most will go over top, but in a high, narrow one more will go around the sides.

4.Stack effect

Stack effect might also be called "chimney effect," and is familiar to anyone who has ever had to deal with the high energy costs of a poorly sealed flue. Normal stack effect is the tendency of air in vertical building shafts to move upward when outside temperatures are much colder than those in the building, and may be the strongest influence operating on air currents on a winter day. It may be explained as follows: as warm air rises to the top of the building due to buoyancy, cold air enters the building to fill that space, becomes heated, and also rises. The rising air causes pressure at the top of the shafts, forcing the air to move out of the building at its top.

The **reverse stack effect** operates in summer, and has the opposite effect . (However, its impact is often less because the temperature differential between outside and inside air is generally not as great in summer). Air-conditioned cold air is relatively dense and tends to sink, so warm air enters near the top of the building to fill its space--which then also becomes cooled and sinks. Pressure develops near the bottom of the building, where air is forced out.

In predicting smoke movement where either normal or reverse stack effect is significant, it is helpful to locate the **neutral plane**--the elevation at which pressures inside and outside a building shaft are equal. While we generally conceive of the neutral plane as a single plane running through the building, in fact the plane may differ for various shafts that have different temperature influences. We also generally assume the plane is about midway through the building, but if leakage paths are not uniform, the location will not be precisely midheight.

Like the wind effect , stack effect has more impact the taller the building and the "leakier" the building. The amount of temperature difference between the building air and the outside, or between air within and surrounding a single building shaft, is also a critical factor in determining its impact.

5.HVAC

The heating, venting, air conditioning system in a building may contribute greatly to smoke movement, either as an assistant to or an enemy of life safety. Central HVAC may distribute smoke far from the fire area, or aid combustion by a constant supply of air. The system pierces fire-resistive barriers and breaks compartmentation, and is often repaired by means of "poke-throughs" that are never closed. While systems differ and it is important to learn the operating principles of the particular HVAC installed in each major building in your area, three components will be common to all:

a. In the **processing system**, returned air is mixed with outside air and processed by flowing through filters, heating/cooling equipment, and possibly humidification apparatus. It is usually installed on the same floor as mechanical equipment rooms.

b. In the **supply system**, processed air is distributed to all floors via the supply air shaft, through ducts in the plenum. From the supply ducts, it is distributed by air diffusers in the ceiling or grills in walls. Fire dampers may be located in the ducts, usually where the ducts meet the supply shaft and where they pass through fire-rated partitions.

c. In the **return system**, air flows from occupied spaces through return collectors into the plenum, then to the return shaft. It may include fire dampers where the air enters the return shaft and where it flows through fire-rated partitions.

When researching a particular HVAC system to determine how it may affect smoke distribution, the following checklist of questions may be helpful:

a. Determine the location of the mechanical equipment room floors and the zones they serve.

b. Are there any special HVAC systems in the building? (Theaters, public assembly spaces, restaurants, computer rooms, stores, etc.).

c. Is there a central control of the HVAC system? Where is it located?

d. Determine the number of return air shafts and their location.

e. Are the return air shafts common to more than one HVAC zone?

f. Are the supply and return dampers on each floor controllable from a central location?

g. Is there a periphery air supply system? How is it zoned?

h. Is the system protected from freeze-up when outside air below freezing temperature is drawn into the system?

On the basis of this information, you will be able to make an appropriate decision concerning how best to use the HVAC in a fire situation. If you **shut down** the system, you will restrict the supply of air to the fire floor, but you will also restrict the supply to other building sections where occupants may need new air. Also, smoke may still be able to move through the ducts under the influence of other building forces. You may wish to supply fresh air to every floor <u>but</u> the fire floor, placing the system on these floors on 100% supply with no return or exhaust. (It is important to be sure that the air is in fact from the outside, not building air that may contain toxic products. System capabilities vary.)

Finally, you may wish to consider placing the fire floor on 100% exhaust mode, no supply, if the system has this capacity (most older systems do not). This would create a "pressure sandwich"--negative on the fire floor, positive on all others--that would aid in restricting smoke movement. You would first need to consider, however, where the exhaust fans are located in relation to the fire--will they pull the fire across a wide space, increasing damage, or toward operating forces? Also, if temperatures are high enough to shut down the fire dampers, smoke spread may increase.

Note that smoke generation in a fire typically exceeds the capacity of an ordinary HVAC system to remove it. Unless specially adapted for smoke control, the system can at best triple usual air flow rates, while smoke removal is estimated to require five to 10 times the normal air return rate.

6.Smoke management systems

Building designs that have given careful thought to smoke management may elect **passive** smoke management or the **active** option of smoke control. A passive system includes any use of the physical arrangement of building space to facilitate smoke movement, whether through barriers, curtains, gravity venting, smoke-proof towers, smoke shafts, or smoke reservoirs. Active smoke control, on the other hand, refers specifically to the use of air flows and pressure differences generated by mechanical fans to restrict smoke movement across given barriers. System capabilities differ as to the number of doors that may be opened without impairing effectiveness, so it is important to know the design constraints of a given system. They may be effectively used to facilitate occupant escape and firefighter access, as well as restricting spread to new areas; however, they are no substitute for sprinklers.

B. Special Problems with High-Rise Structures

Several diverse problems pertaining to high-rise structures deserve special attention. First, there is the problem of heat, which is retained by concrete. Frequent relief for firefighters is essential in such structures, especially if it is necessary to climb several floors carrying special equipment. **Communications** also deserve special attention, and a well-organized command structure will be essential for a complex high-rise operation. (Steel often interferes with radio communication, so you will want to test your equipment on site).

Elevators have often been "called" to the fire floor, posing serious hazards to their riders. Elevators require special designs to prevent this occurrence. If at all possible, you will want to plan some means of securing fire department emergency control of elevators while the building is being designed. Also, personnel may be trapped in the elevator, a contingency some fire departments meet by storing forcible entry equipment on elevators or including it with high-rise emergency equipment.

Core construction provides multiple channels for vertical fire or smoke spread, and may allow spread from one major channel to another. It also increases the possibility that all elevators may be inoperable at once. Watch for scissor stains where two stairways are housed inside the same core enclosure, separated by fire-resistive construction. Typically, doors alternate sides of the core from one floor to the next. This may result in disorientation when climbing several floors. An additional problem associated with core construction is the "doughnut effect," a situation that may occur in poorly ventilated buildings when the fog stream chases the superheated products of combustion around the core, so that they return to the firefighters.

Venting is no simple problem in high-rise structures, and there are no absolute solutions applicable to all occasions. A few general points may be helpful, however:

1. Where normal stack effect is operative, top venting may relieve smoke congestion on the upper floors. (Some fire analysts believe top venting could have saved at least half the lives lost in the MGM Grand Hotel fire, since most deaths were from smoke inhalation on the upper floors.)

2. With normal stack effect, bottom ventilation will often increase the effectiveness of top ventilation. This technique may be used to clear a needed stairway, for example.

3. Where **reverse** stack effect is operative, an open door beneath the neutral plane without top ventilation will draw smoke toward it, possibly increasing smoke congestion.

4. A small sample vent beneath the fire floor will aid in situation assessment.

5. Venting the fire floor with a **high** fire and **high** outside temperatures will usually **not** improve conditions.

6. Venting the fire floor with a **low** fire and **low** outside temperatures also will **not** usually improve conditions.

C. Sprinklers and Smoke Movement

Sprinklers generally have an excellent performance record. They are unfortunately dependent on humans, however, for correct design and installation. It is up to you as a firefighter to recognize this critical ally's powers and limitations.

Sprinklers are thermally operated (except for those designed as special systems). Consequently, there may be considerable smoke development prior to sprinkler activation. Once they do operate, they may even cause additional smoke generation. They primarily affect smoke movement in two ways:

1. Smoke discharge (generally a hemispheric pattern) will cool the air space immediately around and under the sprinkler. This will tend to "darken" the smoke and force it toward the floor.

2. Sprinkler discharge may form a "curtain" or partial barrier to smoke movement, dependent for effectiveness on favorable relationship to the smoke source, building configuration, and the intensity of the "thermal push" driving the smoke.

An appropriate sprinkler design must consider the size of the space to be protected, the type of materials expected to be placed in the protected place, the spatial configuration, and the adequacy and reliability of the water supply. Systems may be overdesigned, resulting in excessive delivery and water damage. Often they are underdesigned, or occupancy changes increase the fuel load. Sometimes, too, partial protection is installed in a way that is of little help in the actual fire incident.

Poor installation and maintenance are common human errors that may impede sprinkler effectiveness. Other factors in poor performance include sabotage, frozen pipes, faulty building construction, and obstruction to water distribution. When inspecting a sprinkled building, it is important not to take proper functioning for granted. If you arrive on the fire scene to discover the sprinkler system requires activation, it is almost always worthwhile to attend to it first: you will need to fight your way to the seat of the fire, but the sprinkler system is already there.

D. The Atrium as a Special Problem

An **atrium** may be defined as a court that pierces the floors of a multistory building and extends to the roof. They are usually covered, often by a skylight, and are typically used to create an effect of light and spaciousness. In the event of fire, atriums offer a ready channel for vertical extension of fire and smoke, and in some cases may spread smoke to multiple floors. A number of smoke management options are currently being tried for atriums, but little experience is presently available to determine the best way to control smoke spread in long multistory shafts; sprinklers alone may only cause the smoke to clog midway down, or may be too distant from the seat of the fire for effective control. Their placement must be carefully planned. Often other passive or active smoke control options must be examined for use in conjunction with sprinklers. Until more research and experience are available, it is best to take an extremely cautious approach to atriums and take as little for granted in prefire planning as possible.

UNIT FIVE: SPECIAL PROBLEMS OF BUILDINGS UNDER CONSTRUCTION

A. Hazards and Operational Impediments

When is a building not a building? When it's under construction. Numerous problems make fires at this stage a particularly hazardous prospect, and almost nothing, from access to stability, is a "sure bet."

Exterior access problems vary from day to day as new materials arrive and waste accumulates. It is important to try to work out an arrangement with the builders that will allow you to reach the building. **Temporary roads** may be of no use in snow or rain.

Structural access is not only difficult, it is likely to pose definite threats to the lives of those unfamiliar with the building. Barriers and walls may be omitted around floor openings; temporary propping and bracing may be used for heavy items; confusing ingress/egress patterns are likely; and the presence of numerous materials may block access, cause tripping, or make surfaces slippery. The best possible lighting is essential as is careful guidance from personnel thoroughly familiar with the building.

Fire protection and water supply may be out of service in entirety or in part. Slag and oils from welded piping may block hose nozzles and damage lining. The standpipe system may not be capped at the end of a working day, or hose outlet valves may be left in open position. Hydrants are likely to be useless. Sprinklers, fire alarms, and communication systems are unlikely to be operative until the building is nearly complete.

Numerous **hazards** are posed in the constantly changing building environment: electrical shock hazards, walk-offs, poor visibility due to inadequate lighting (just when you need it most) and tripping hazards from oil, mud, and water, or loose construction materials (just when you need them least).

B. Combustible/ Explosive Materials

With all the reasons you have for wishing to avoid any fire problems with a building under construction, there are plenty of factors that make it possible you will be called there. Combustible materials abound at the site, including trash, falsework, temporary structures, and finish materials. **Ignition sources**, including heating devices, torches, cigarettes, and temporary electric wiring, are also in good supply.

If a fire does begin, there is no lack of material to complicate it. The numerous machines present on the site may use gasoline, diesel fuel, or liquified petroleum gas, sometime stored in great quantities. Containers for this fuel may explode or become projectiles. Compressed gas may also be present, usually in limited quantities, for use in equipment such as welding carts or paint sprayers, and may worsen the fire situation or otherwise threaten personnel safety.

Explosives are, of course, a major concern. On a rocky site, it is best to begin with the assumption that blasting is or has been in progress. An explosive mat or magazine (usually red) is a clear-cut indication that you need to begin information-gathering: Where are all the explosives? How much is there? How much has been used? Though not permitted by code, it is always possible that blasting caps may be stored with explosives or that dynamite may leak nitroglycerine. For all these reasons, it is up to you to devise the best plan you can for getting quick, accurate information in an emergency.

C. Steel and Concrete Under Construction

In steel construction, fire protection is unlikely to be complete. Often fire protective coating is omitted from the lower floors until late in construction, so that it will not be knocked off. This means the supports for the building may be undermined by a fire in the lower floors--where debris, materials, equipment, and gas cylinders are commonly located.

"Field bolting," the use of bolts for steel connections until they can be replaced by rivets, lessens the stability of a steel structure, especially in wind.

In concrete construction, there is always the question of what stage has been reached in curing the concrete. Should green concrete be exposed to fire, total collapse may be expected. While a finished building is often expected to withstand the collapse of one floor, it may not do so when concrete has not achieved full strength. **Progressive** collapse has occurred in such situations, as in the 1973 Skyline Towers collapse in Arlington, Virginia. Falsework collapse often occurs, and most falsework is flammable.

Post-tensioned concrete is a particular hazard, since until the tendons are "jacked" (tightened), structural support really depends on the falsework. There is no bond between the concrete and the tendon (which is kept in a sheath to prevent bonding) until tensioning is complete. Therefore, the concrete may feel hard and walkable, but is in no way comparable to regular reinforced concrete at this stage; it is more comparable to a thick sidewalk with nothing under it. It is possible that several floors at once may be supported by falsework. Also, tendon ends may remain exposed to fire, or the tensioning may be done in increments so that full strength has not been achieved. Remember that the type of steel used in tendons loses strength and fails at a lower temperature than other types. In one midwest city an entire 18-story post-tensioned structure collapsed as a result of a falsework fire.

Precast concrete is unstable until connections are complete, and relies on temporary bracing or shoring. The loss of such bracing may cause total collapse. In tilt-up construction, temporary braces are required for stability until the roof is tied in. **Cantilever platforms**, also, are commonly braced by wooden shores; a large collapse zone should be clear where they are endangered. **Excavations** braced by unprotected cable or rods may also pose collapse hazards where formwork or debris may heat the cables.

Bear in mind that, after the fire, the concrete will almost certainly be torn down. There is no need to take extraordinary risks with human lives to save a structure that may already be condemned.

D. Non-fire Collapse Scenarios

Buildings under construction, as we have seen, are high risks for collapse incidents--with or without fire. The fire department may be called in to perform rescues, to protect the public from weakened walls, or to fight any fire that may follow structural failure. The fire department's role requires definition in such cases. It is essential that you make a point of clarifying the limits of your authority **before** the incident. Under construction collapses are likely to be followed by an assortment of lawsuits, with each party attempting to cast blame elsewhere. Your department will need to be prepared to defend itself from charges that its actions precipitated or worsened the collapse.

It is therefore advisable that the department form working relationships with structural engineers in the area so that they may serve as advisers on building stability. For rescue to be successful, careful technical analysis of shoring is an absolute necessity. Fire officers should also be careful not to authorize demolition of the structure, since the structure as it stands may yield evidence clarifying liability.

The principles of structural behavior apply equally to standing buildings and those that have suffered a partial collapse. However, in the former case structural failure is only a possibility. Once it occurs, loads and forces are greatly complicated, and no load is "designed." Further collapse is always a possibility, and may be precipitated by rescue attempts in which building parts are moved without recognizing the result of movement.

Structural collapse can occur under three basic scenarios:

1. During construction, most frequently as a result of inadequate bracing, premature removal of supports, or concentration of building materials or contractors' equipment.

2. When a building is under demolition due to a gradual loss of structural integrity. Occasionally souvenir-seekers may remove vital parts and precipitate collapse sooner than planned.

3. During the normal life of a building from overloading, vehicle impact, unqualified alterations, fire, or other causes.

A collapse incident requires excellent teamwork between concerned agencies--the kind of teamwork that can be promoted only by a clear working plan with which all parties are familiar. The articles on collapse by Francis Cruthers and Jerry Laughlin included in the appendix of this course testify to the importance of such a plan, as well as providing other first-hand advice from those who have been there. A collapse scene is no time for the fire department to try to

give a solo performance. Proper notification of concerned agencies--public utilities, city agencies, and private industry--is a must, and will obviously be easier if the department has an updated list of needed numbers already at hand. Coordination is required with persons familiar with the building, especially the foreman. You will need to get the best possible data on the exact stage of construction, possible leakage problems related to gas and electric utilities, and the location of fuel, explosive, or toxic substances.

Adequate personnel and equipment are obviously essential and must be obtained by existing agreements--medical aid and ambulances, rescue units and equipment, mask service and field communications unit, and floodlight (remember the special hazards of operating in "under construction" facilities with poor lighting).

To conduct such complex operations without a clear command structure can only be described as foolhardy. Freelancing companies will endanger their own lives and those of others. There must be one person in charge and a clear line of command, with crystal clear and rigorously followed reporting procedures. Personnel must be trained to communicate up, down, and sideways, with each officer providing a full report when relieved of command and adequate notification provided to all incoming units. The awareness of the exact location and purpose of all personnel will be critical to avoid injury and loss of life.

The special problems of such an incident can only be dealt with by planning--the sort of planning that cannot be done by the fire department alone, but with the cooperation and understanding of all parties that may become involved.

UNIT SIX: ADDITIONAL INFORMATION ON CHANGE AND PREVENTION

A. Promoting Fire-Safe Buildings

In your attempts to influence your community to adopt fire-safe building practices, you will find yourself dealing with diverse groups with widely different interests and expertise. These include architects, construction companies, engineers, the fire marshal's office, the building department, political or citizens' groups, and the prevention and operations division of your own department. You will want to discover the most effective ways that you can appeal to common interests without putting them on edge, so that you can approach problems as a creative team.

The Memphis Fire Department has found it helpful to advertise its availability as a consultant when buildings are in the planning stage, pointing out that this will minimize lengthy approval delays. In San Francisco, a building construction committee functions as a subgroup of the Chamber of Commerce, which lends political clout and the appropriate tie to community welfare. Its members include building inspectors, fire officers, architects, and engineers.

It is important to be as sure of your facts as you can in dealing with such groups , and to respect their expertise without being "snowed" by it. A reputation for costly and unnecessary requirements will hamper your efforts; a willingness to suggest compromises that will meet the public interest and bear in mind the problems of the construction company, for example, will greatly enhance the willingness of others to take your advice seriously.

B. Conflict

Thomas and Kilmann have described five basic "conflict resolution" styles. The **avoidance of conflict,** or a tendancy to **give in regularly**, are two that will obviously not further your interest. **Competition**--a tendency to put "you" against "them" in a power struggle--often leaves a legacy of bitterness in the loser, and a wish to "get even" that may be satisfied behind the other party 's back. **Compromise**--meeting some interest of one side and some of the other--is often the best approach, but it may leave some important needs unsatisfied, which you can ill afford to do if your cause is life safety.

Cooperation--a creative attempt to meet the needs of both sides through problem solving--may yield the most satisfactory solutions. For example, in one major city, a theater wished to stage a production in which piles of combustible materials were arranged on a stage projected into the audience and around the theater. The object was to simulate a junkyard. Working with theater representatives, the fire department found it was possible to plan a way of embedding concealed sprinkler heads invisibly in the "junk" so safety was protected. Cooperative efforts like this take time--time to cultivate good working alliances as well as time to save special problems--but may be richly rewarded in improving the fire safety of the community you protect.

Appendix D

BIBLIOGRAPHY

BIBLIOGRAPHY

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- John Mittendorf, "Ventilation Techniques for Conventional Roofs," American Fire Journal (January, 1984) p. 14.

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  A tactical exercise and discussion of a cellar fire in a balloon frame multiple dwelling.

- Matthew Murtagh, "Introducing a New Series by Matthew Murtagh," Firehouse (September, 1980), p. 30.

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